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A STUDY OF LEMANEA IN INDIANA WITH NOTES ON ITS DISTRIBUTION IN NORTH AMERICA[1]

By C. Mervin Palmer

Collections of the fresh-water alga, Lemanea, were made by the writer in 1930, in Jackson and Lawrence counties, Indiana. In attempting to identify this material, considerable difficulty was encountered for it did not agree with published descriptions of any species. Not only did the taxonomy of the alga constitute a problem, but, as other locations for the plant were discovered, it became apparent that the alga was widely distributed over the southern part of the state, and a study of its distribution in that area was begun. Approximately 150 collections have been made in Indiana from 81 locations in 18 counties. All of these have been studied with particular attention to characters of taxonomic importance, together with a consideration of their distribution in relation to geological formations. In accumulating specimens of the genus from elsewhere for comparison with those from Indiana, many new and unrecorded locations and observations of taxonomic interest for it over the country have been revealed.

Lemanea was named in honor of the French botanist, Dominique Sebastian Leman, who lived from 1781 to 1829. The genus name was first used by Bory in 1805 but in a broader sense than it is now recognized, the present description being that first given to it by Agardh in 1828. The genus contains two subgenera, Sacheria and Eulemanea. Sacheria has antheridia in papillae; carpogonia and carpospores are developed primarily in the nodal zones and the central filament in the sexual shoot is naked, that is, it is not closely surrounded by other filaments. Eulemanea, on the other hand, has antheridia in continuous or broken bands, one band on each node; the carpogonia and carpospores are developed primarily in the internodes, and the central filament of the sexual shoot is tightly inclosed by a group of spirally wound filaments. These distinctions are so constant that no difficulty is encountered in separating plants into the two subgenera.

Atkinson (2, 3) has contributed most to the taxonomic study of the American forms of Lemanea, although both Wood (21) and Wolle (20) had previously listed a few locations for the alga in the United States. The earliest collections of Lemanea for North America were stated by Atkinson (3) to be those from Kentucky by Dr. Peter in 1834 and Dr. Short in 1842; but there is to be found in the first section of volume 2 of Agardh's Species Algarum, which was published in 1828 (1), a description of *"Lemania variegata"* collected in North America on exposed rock in a river in Virginia, and sent to Europe by Muhlenberg. This was probably the early Pennsylvania botanist, G. H. E. Muhlenberg, who lived from 1753 to 1815. Agardh's description of this material indicates that it belongs to the subgenus Sacheria. If American plants of this subgenus should again be separated into a species distinct from the European material, this name, *L. variegata,* probably should receive precedence over any more recent one. The writer has found one specimen of Lemanea from Muhlenberg's collection of plants which is in the herbarium of the Philadelphia Academy of Natural Science. The label on the specimen gives no information as to its origin, but one can presume that it is the collection made in Virginia and referred to by Agardh.

Taxonomic work on the genus has been listed, and even today there is no agreement as to the number of species represented. European writers have generally recognized from five to seven species of the subgenus Sacheria and five species of Eulemanea. Atkinson (2, 3) has combined some of the species of Sacheria and described additional species of Eulemanea so that North America is generally credited with two species in Sacheria and eight species in Eulemanea. Atkinson's reason for combining the several species of Sacheria for North America was that plants available showed no distinct lines of demarcation in the characteristics which have been emphasized in Europe as bases for the separation of the species.

The ten species listed for North America are *L. fluviatilis* (L.) Ag., *L. fucina* Bory, *L. annulata* Kütz., *L. australis* Atk., *L. catenata* Kütz., *L. grandia* (Wolle) Atk., *L. mexicana* Kütz., *L. nodosa* Kütz., *L. pleocarpa* Atk., and *L. torulosa* Sirodot. The first two belong to the subgenus Sacheria and the other eight to Eulemanea.

The distinguishing features of the several species (as interpreted by the writer) are as follows. The sexual shoot of *L. fluviatilis* is

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violet in color and the carpogonia and carpospores are developed in both the nodes and internodes. In *L. fucina*, as described by Atkinson (2), the sexual shoot is green and the carpogonia and carpospores are limited to the nodes. *L. annulata* has a sexual shoot which is deeply and evenly undulate; the wall is delicate and appears thin, and the antheridial ring is wide and lighter in color than the surrounding tissue. *L. australis* has a sexual shoot variable in surface form, green in color, and with an antheridial band which varies in width and margin. One outstanding characteristic of this species is that the Chantransia filament increases in diameter from 30 microns at the base to the unusual width of 50-120 microns at a distance above the base. *L. catenata* is characterized by its abrupt and somewhat angular nodes and cylindrical internodes, is olive-green to violet in color, and has narrow antheridial bands with irregular margins. *L. grandis* has a plane to slightly undulate margin, is olive-brown in color, and the antheridial band is broad. Its carpospores are large in size, and the wall of the sexual shoot is rigid on mature specimens and brittle when dry. *L. mexicana* is similar to *L. grandis* in surface form, color, and antheridial band. The texture of the wall of the sexual shoot, however, is subcartilaginous and the carpospores are not described. *L. nodosa* has a medium to deeply undulate surface, although the nodes may frequently be knotty, that is, abrupt and with an irregular surface. It is black-violet in color, and the antheridial ring is broad and with an irregular margin. *L. pleocarpa* has a shallowly undulate surface and is probably violet in color. Its antheridial band is variable in width and regularity of margin. The outstanding characteristic is that while the procarps are more abundant in the internodes, they are also present in the nodes. *L. torulosa* has a plane to shallowly undulate surface; the color is olive, and the antheridial rings are narrow, irregular in margin and are often discontinuous.

Few workers find it possible to identify with any degree of assurance the American specimens of Lemanea species. With one exception, the American collections of Sacheria are placed by Atkinson (3) in the species *L. fucina*, and yet the material varies to such an extent that it covers the description of several European species. There are several collections which also show very definitely an intermediate condition between *L. fucina* and the other species of Sacheria listed for America, *L. fluviatilis*. In the other subgenus, the identi-

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fications are no less confusing. All Eulemanea collections from the southeastern states have been listed as *L. australis* by Atkinson, primarily because of their proximity to the location for the type material of that species. Much of the material from the central Atlantic coast states also has been given only tentative identification, generally as *L. torulosa*.

The confusion of species is particularly evident in material collected in Indiana. In 1897, Underwood (19) published a list of cryptogams for Indiana which included *Lemanea catenata* from Eel River Falls, now known as Cataract Falls, Owen county, Indiana. Duplicate material of this collection was widely distributed for it was placed by Collins, Holden and Setchell as number 237 in the exsiccati of North American algae, entitled Phycotheca Boreali Americana. In 1931, Atkinson (3) listed Underwood's Lemanea as *L. annulata* with the statement that "this material was formerly determined as *L. catenata* but a re-examination shows that it is *L. annulata*." In 1932, B. H. Smith (18) listed Lemanea from the same locality in Owen county as *L. torulosa*. In 1933, Palmer (12) listed several locations for the alga in Indiana and suggested that six species, *L. annulata, L. catenata, L. nodosa, L. pleocarpa, L. torulosa* and *L. australis* were apparently represented in the state. In 1934, several collections of Indiana Lemanea were sent by the writer to Dr. H. Skuja, who identified most of them as *L. nodosa,* and allowed others to remain as *L. catenata* and *L. pleocarpa*. Atkinson (3) has designated material from the neighboring state of Kentucky as the type material of *L. pleocarpa*.

It became apparent that the plant in Indiana varies considerably even in the same locality and that it has several of the outstanding characteristics of five or six of the species of Eulemanea. The light-colored antheridial ring of *L. annulata,* occasionally the cylindric internodes and abrupt nodes (the "dumb-bell" surface form) of *L. catenata* and the deep undulate form, together with wide irregular antheridial rings of *L. nodosa,* the occasional presence of carpogonia and spores in the node, as in *L. pleocarpa,* and the small olive-brown forms with almost plane surface, as in *L. torulosa,* are all to be found in Indiana collections. Many examples of the occurrence of several of these distinctive characteristics of the different species on a single sexual shoot have been encountered.

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Thus, the Indiana material does not appear to fit exactly any of the species so far described and pending a detailed study of more specimens, particularly from southeastern United States and from Europe, its taxonomic status in relation to other species is being left undecided. It is found to be readily divided into two related types. These two types are here designated as the "Becks Mill" type and the "Jackson" type. The former is the more common, being found at 77 of the 81 stations in Indiana, in two stations in Kentucky and one in Tennessee. The Jackson type resembles the other except that it is early maturing, dwarf and less deeply undulate. It is limited to four stations, one in Jackson county and three just across the county line in Lawrence county. In the discussion which follows, the two types are considered separately only when the characters in which they differ are being considered.

RANGE IN VARIATION OF TAXONOMIC CHARACTERS OF LEMANEA IN INDIANA

In the present work a taxonomic study of approximately 150 collections of Lemanea from Indiana has made it possible to determine the range in variation of characteristics which have been used previously to differentiate between the species. At several locations in the state, material has been collected at different seasons of the year and a fairly complete record of the development of the plant, therefore, is available. In addition, a study of over 150 collections obtained from other states and Europe has made it possible to compare the Indiana material with that of all other American, and some of the European species.

Observations have been made and records kept with regard to the following characteristics of all Lemanea specimens studied:

Sexual shoot: color when wet; color when dry; maximum length; common length; range in diameter of node; range in length of internode; surface form; attenuation of base; branching; number of rows of cells in the wall; thickness of wall; character of the central stran.

Antheridial ring (or papillae): diameter when young (when antheridia are present); diameter when old; form; margin; color; distinctness.

Carpospores: abundance; location; shape; diameter; length; time of appearance; time of maturity; time of germination.

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Filamentous (*Chantransia*) *stage*: abundance; color; branching; form; height; diameter; origin of sexual shoots.

Color of the sexual shoot. When the sexual shoot of Indiana Lemanea is first developed in the fall or winter it is green, but soon changes to green violet. This color remains from late November until late spring, at which time the shoot begins to turn brown. While the brown color is not due entirely to the carpospores, its appearance coincides with their development. During the early part of the summer, the shoot is brownish-violet but by July, most of the violet has disappeared and the shoot is brown for the remainder of its existence. Shoots, when dried, become dark and the violet color is more likely to be evident than it is in the fresh specimens or in those kept in liquid preservatives. The older shoots, when dried, are brown to black, although some of the violet color may often be present especially near the base.

In collections representing the Jackson type, the change from green-violet to brown occurs about the end of April, one month earlier than in the Becks Mill type. Table I indicates the differences in the time of color change in the two types.

Very few early spring collections of Eulemanea outside of Indiana are available for comparison with the Jackson and Becks Mill types. Theoretically, *L. australis, L. torulosa* and probably *L. grandis* and *L. mexicana* are some shade of green during the spring, while *L. annulata, L. catenata, L. nodosa* and possibly *L. pleocarpa* are more commonly violet. The shoots of all species of Eulemanea become brown to black during the summer.

In the subgenus Sacheria, practically all American material is green with only an occasional evidence of the violet tint. The green does not give way to brown until late in the summer. The European collections of Sacheria studied are violet in most cases and are seldom

TABLE I

Time of color change in sexual shoots of Lamanea in Indiana.

| Month | Color of sexual shoot | |
	Jackson type	Becks Mill type
November	Green	Green
February	Green-violet	Green-violet
April	Brown-violet	Green-violet
May	Brown	Brown-violet
July	Brown	Brown

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green. The violet color is present even in the mature shoots during the summer. Atkinson emphasizes this color difference in distinguishing between the common European species, *L. fluviatilis,* and the common American species, *L. fucina.*

Length of sexual shoots. Material from Indiana ranges in length of shoot from less than 1 cm to 20 cm. The longest specimens are not the very mature ones found in the fall but are those collected from March to July, when approximately one-third of the collections show a maximum length of 10 cm or more. As a general rule the longest specimens are found in deeper water and in the larger streams. Shoots of the Jackson type are all short, never reaching more than 5 cm.

Of the collections of Eulemanea outside of Indiana, only 3 have a maximum length of 9 cm or more, and 2 of these are from Kentucky and Tennessee and belong to the Becks Mill type. Except for this type the Eulemaneas of eastern North America are short and seldom exceed 5 cm in length. In Indiana approximately one-half of the collections have a maximum shoot length of more than 5 cm.

In the subgenus Sacheria the American material is short; in only one instance is the maximum length over 9 cm. This is in contrast to the European Sacheria where more than half of the collections studied have a maximum length of over 10 cm.

Diameter of the nodes. The diameter of the nodes in the Indiana material is comparatively large, the maximum diameter in two-thirds of the collections being from 1-2 mm, and more than one-half of these are 1.2 mm or more. In the eastern states, exclusive of Indiana, the only collections of Eulemanea with nodes larger than 1.1 mm are those from Kentucky and Tennessee which belong to the Becks Mill type. The diameter of the nodes in Sacheria is small, the maximum diameter in most of the material being about 0.5 mm.

In Indiana the larger diameter of the nodes is associated with greater length in the shoots. Measurements of the maximum diameter of the nodes and the length of the shoots indicates a relationship between the two which is shown in table II.

The relationship between these two factors is, of course, not a rigid one. Actually the maximum diameter of the nodes will tend to vary for any given length of the shoot. The table indicates the range in the maximum diameter of the node for the collections showing the different maximum lengths of the shoot.

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The most common maximum diameter of the node for collections showing a maximum length of shoot of 2 cm is 0.6 mm and this diameter increases with increase in length of shoot until a length of 14 cm is reached, when the most common maximum diameter of the node is 1.6 mm.

Length of the internode. The maximum length of the internode for collections in Indiana varies from less than 0.5 mm to 5 mm and in general increases with increase in the length of the shoot. The range and the most common maximum internode length for different maximum lengths of the shoot are shown in table III. Thus when the maximum length of the shoot is only 2 cm, the maximum length of the internode is between 0.5 and 2 mm and is commonly 1 mm. At the other extreme, when the maximum length of the shoot is 14 cm, the maximum length of the internode is 3-5 mm, commonly 3.5 mm. The same relationship is found for the Eulemaneas outside of Indiana, indicating that the length of the internode is not a criterion to be used in distinguishing between species unless one species is characteristically long and the other short in length of the shoot.

TABLE II

Range in maximum diameter of the nodes in relation to the length of the sexual shoot in Indiana Lamanea

Max. length of shoot, in cm	Maximum diameter of the node, in mm									
	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
2	xxxxxxxxxxXXXxxxxxxxxxxxxx									
4	xxxxxxxxxxxxxxXXXXxxxxxxxxxxxxxxxxxx									
6	xxxxxxxxxxxxxxXXXXxxxxxxxxxxxxx									
8	xxxxxxxxxXXXXxxxxxxxxxxxxxxxxxx									
10	XXXxxxxxXXXXxxxxxxxxx									
12	xxxxxxxxxxxxXXXXXxxxxxxxxx									
14	XXXxxxxxxxxx									

The lines of x's indicate the range in the maximum diameter of the node in the different collections studied. The large X's represent the most common maximum diameter of the node.

TABLE III

Relation of maximum length of internode to maximum length of shoot
in Indiana collections of Lemanea

Maximum length of shoot in cm.	Maximum length of internode, in mm.									
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
2	xxxxXXXxxxxxxxxx									
4		xxxxxxxXXXXXxxxxxxxxxxxxxxxxxxx								
6		xxxxxxxxxXXXXXxxxxxxx								
8			xxxxxxXXXXXxxxxxxxxx							
10			xxxxxxxxxXXXxxxxxxxxx							
12			xxxxxxxxxXXXXXxxxxxxxxxxx							
14				xxxxXXXxxxxxxxxxxxxxx						

The range in the maximum length of the internode is shown by the lines
of x's. The large X's show the maximum length of the internode which is most
common for each maximum length of the shoot.

Surface form of sexual shoot. In the various species of Eule-
manea the surface of the sexual shoot may be plane, shallow-,
medium- or deep-undulated, or shallow-, medium- or deep-"dumb-
bell-shaped." In the undulate forms the crests of the nodes may be
rounded and smooth or they may come to a ridge; in the dumb-bell-
shaped forms the knobs may be smooth or gnarled. The character
of the surface has been much emphasized in distinguished species as
the following list showing the typical condition for each (as inter-
preted by the writer) indicates:

L. grandis—plane (to shallow undulate)

L. torulosa—shallow-undulate (to plane)

L. pleocarpa—shallow-undulate (to medium-undulate)

L. annulata—medium to deep, smooth-undulate

L. nodosa—medium to deep, smooth to ridged-undulate

L. catenata—medium, ridged-undulate to dumb-bell-shaped

L. australis—medium to deep, smooth-undulate with tip and base
almost plane.

The Indiana collections show sexual shoots which are most often
medium, smooth-undulate, resembling *L. annulata* and *L. nodosa* in
this respect. The Jackson type, however, is definitely shallow-undu-
late as in *L. torulosa*. In the collections of the Becks Mill type, one
finds frequently, in addition to the most common form, the deep-
undulate, and the shallow- to deep-dumb-bell-shaped thalli with both
the smooth and the gnarled surface at the node. The tips of the

EXPLANATION OF FIGURES

Figure 1. Indiana Lemanea, Becks Mill type, spring condition. The sexual shoot was collected in March, at Becks Mill, Washington county, Indiana. It has distinct antheridial rings at the nodes. Camera lucida drawing. (a) Tip of sexual shoot. (b) Portion below the tip. (c) Middle portion. (d) Basal portion.

Figure 2. Indiana Lemanea, Becks Mill type, summer and autumn condition. Collected at Becks Mill, Washington county, Indiana. Camera lucida drawings. (a) Middle portion of sexual shoot collected in May, showing young cystocarps in the internodes. (b) Middle portion of sexual shoot collected in September, showing mature cystocarps in the internodes.

Figure 3. Indiana Lemanea, Jackson type, early spring condition. Material collected in March, from Guthries Creek, Jackson county, Indiana. Antheridial rings are visible at the nodes. Camera lucida drawings. (a) Tip of sexual shoot. (b) Middle portion. (c) Basal portion.

Figure 4. Indiana Lemanea, Jackson type, late spring condition. Material collected in April, from Guthries Creek, Jackson county, Indiana. Masses of maturing cystocarps are present in the internodes, causing them to be dark in color. Antheridial rings are no longer visible. Camera lucida drawings. (a) Middle portion of sexual shoot. (b) Basal portion.
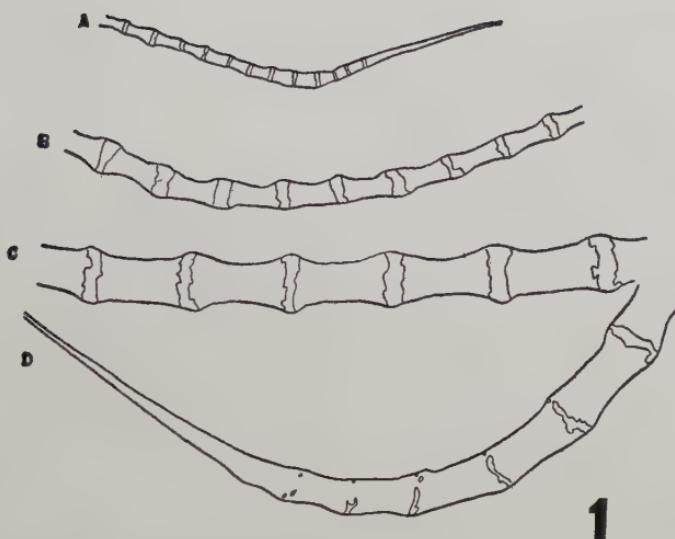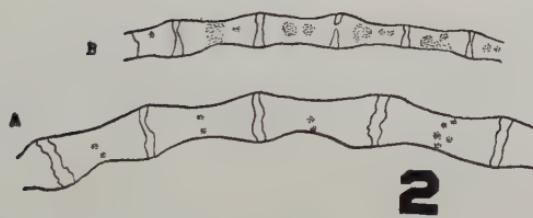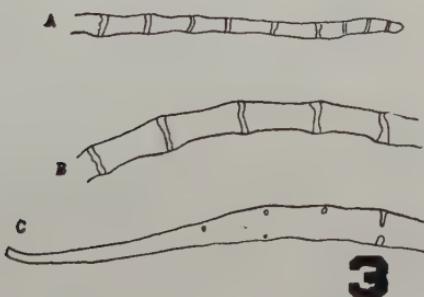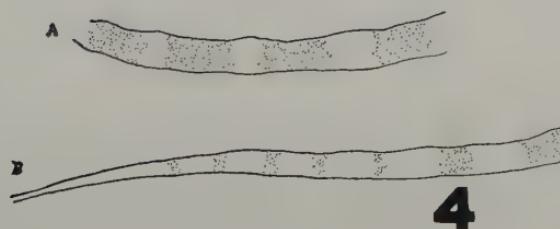
shoots are very often dumb-bell-shaped. Thus the Indiana material varies from the *L. torulosa* form, through the *L. nodosa* and *L. annulata* forms to the *L. catenata* form. With such variation, it can be seen why the Indiana material has been identified at various times as each of the above species.

Figures 1-4 show the surface form of the sexual shoots in the two types of Indiana Lemanea. In figure 1, the shoot of the Becks Mill type is seen to have the medium-undulate surface, with the exception of the tip, where, in the specimen shown, it is almost plane. In figure 2, material from the same location is shown as it appears during the summer and fall, the cystocarps in the internodes being visible through the wall. The surface of the shoots tends to remain undulate. Figure 3 shows the young shoots of the Jackson type, where the surface is shallowly-undulate. The cystocarpic strands of this early maturing type, as illustrated in figure 4, were collected in April.

Base of sexual shoot. All species of Eulemanea are alike in the absence of a distinct basal stipe and the Indiana types of Lemanea are typical of Eulemanea in this respect. In the Sacheria material studied, the base is generally stipitate, the stipe being cylindrical with a sudden increase in the diameter of the shoot from the stipe to the fruiting portion above.

Branching of the sexual shoot. In some species of Sacheria abundant branching of the sexual shoot is found, but branches are absent or rare in Eulemanea. In Indiana, branches are found in about one-fourth of the collections but they are never numerous and often appear to have been developed in response to an injury to the sexual shoot, for they are short, abrupt in their origin and in most cases are near the tip. The shorter sexual shoots are almost always unbranched. Branches are absent in the Jackson type and are very rare in the Eulemanea outside of Indiana.

In the European Sacheria, only one collection of the 19 studied lacks branches, and the branches are generally abundant and well distributed. In American Sacheria, branches are often present but they are seldom numerous.

Texture of the sexual shoot. The inner part of the wall of the sexual shoot is composed of 2-3 layers of large cells which, in most species of the genus, are compactly arranged; but in the specimens of *L. annulata* from western North America, the writer has observed

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that these inner cells of the wall are more loosely aggregated. This causes the wall to appear thin and delicate or "papery." Measurements show that the wall in the western specimens is as thick as in the other species, and the thin appearance of the wall in *L. annulata* is due solely to the loose arrangement of the cells.

The Indiana Lemanea is not of the *L. annulata* type but has a leathery texture and the inner part of the wall shows cells which are compactly arranged. Frequently, the shoots are also quite slimy, especially in the spring, and their tips are likely to stick to paper on which they are being dried.

Antheridial ring. The antheridial ring at the nodes of the sexual shoot is of considerable taxonomic significance in the Indiana material because it shows a white or yellow color during the period in the spring when the antheridia are functioning. Since *L. annulata* is the only species described with a light-colored ring, it is probably this character more than any other which caused Atkinson to consider Indiana Lemanea as *L. annulata*. However, the ring for that species is wide and has an even margin, while Indiana specimens have a ring which is highly variable in width and whose margin is commonly irregular, (figure 1).

The light color of the ring is present from February until early in May in the Becks Mill type and until the middle of April in the Jackson type. In the late spring the antheridia disappear and the rings change to a brown color and are then darker than the surrounding tissue. The brown ring tends to become less distinct with age.

The rings are generally continuous but in many of the collections, incomplete rings may be present on some of the nodes. A study of young shoots indicates that antheridia first develop in small isolated spots on the node and these spots enlarge until they merge to form the continuous ring.

The width of the antheridial ring in the Indiana material varies over a large range which is much greater than that for any other eastern American Eulemanea. In one-third of the collections from Indiana, the maximum width of the ring is intermediate between the narrow ring of *L. torulosa* and the wide ring of *L. annulata, L. nodosa* and *L. catenata*; that is, it is between 200 and 300 microns. However the range in width for all of the Indiana specimens is from less than 100 microns to more than 600 microns.

Location of carpogonia. Carpogonia are normally present, in Indiana material only in the internodal zones, but in a few collections they are present in the nodes as well as the internodes. This more general distribution of the carpogonia and cystocarps is to be found in one collection from Clark county, two from Decatur, two from Owen, and one from Ripley county. This characteristic was considered by Atkinson to be so distinctive that he described a new species, *L. pleocarpa,* on the basis of its presence in a few specimens of Eulemanea from Kentucky. From the observations made in Indiana, it seems probable that the more general distribution of the carpogonia in Eulemanea merely represents an occasional departure from the normal condition in which carpogonia are restricted to the internodes, and that it is not a distinct type to be separated as a new species.

Carpospores. In Indiana material carpospores begin to appear in some collections about the first of April and by the end of that month, all collections show them to be present. During May, most of the spores appear to be young, that is, they are still attached in filaments and their walls are thin. By July, many appear to be mature, with heavy walls and dense protoplasm. Germinating spores within the sexual shoots are frequently found from September until February. One, and sometimes two germ tubes per spore are produced. In the early-maturing, dwarf type, here called the Jackson type, germinating spores are seen in material collected as early as May and even during the last of April.

The spores are found in abundance and, while they are commonly oval, spherical, ovate, cylindric and irregular forms are also present. They differ in particular from the spores of *L. fucina* which are elliptical and quite uniform. Mature spores of Indiana Lemanea average from 23 to 33 microns in diameter and from 27 to 41 microns in length. However the size is variable and is found ordinarily to range from 16 to 45 microns, with two collections showing a still greater maximum diameter. One of these two collections was made in late May in Crawford county. The immature spores were 22-66 microns in diameter and 44-61 microns long. They appeared to be normal in every way except in size. In the other collection, made in western Lawrence county in May, the spores reached a maximum diameter and length of 90 microns, but it is quite evident that this enormous size was due to the presence of a parasitic fungus whose spores and

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mycelial filaments could be seen in practically every carpospore. Again it may be significant to note that the one particularly important characteristic of *L. grandis* which supposedly separates it from such closely related species as *L. torulosa* and *L. australis* is its large spore size. We have, in Indiana material, good evidence that spore size varies within a species more than has been previously suspected for the spores in Indiana more than cover the range of size described for all other species of the genus combined.

Chantransia stage. The filaments (Chantransia stage) produced from the spores grow to a height of 1-4 mm in Indiana. They are abundant from the first of February until the middle of April and can be found to some extent both before and after that period. The color of the filaments ranges through various shades of green and violet. In many cases the filaments are little branched, but in other cases branches are numerous, alternately arranged, and with a tendency for the upper branches to be clustered and unilateral. While the diameter of the filament is not constant throughout, the change is gradual and not abrupt, the greatest diameter generally being near the base while the tips of the branches have the smallest diameter. A considerable number of specimens observed had a maximum diameter of 29 to 33 microns although filaments with portions having a diameter as small as 12 microns and others with a maximum of 45 microns have been measured in the Indiana material. No abrupt change from wide main axis to narrower branches is seen, as is described for *L. nodosa*; and no change from a narrow filament at the base to a much wider one near the tip is present, as is characteristic of *L. australis*.

Origin of the sexual shoot. The sexual shoot arises as a lateral branch of the Chantransial filament. This branch may be located at the base, or just above the base, or, in a smaller number of cases, in the upper part of the filament. In all species of Eulemanea, the most common origin of the sexual shoots is the basal; and this is found to be the case in the Indiana material, for in the collections where the origin of the sexual branch can be observed, basal origins are present in about two-thirds of the cases. Some of the collections show sexual shoots originating at more than one position on the filaments.

There seems to be a tendency for the material from the more southerly counties (Jefferson, Scott, Clark, Harrison and Ripley)

to have sexual shoots at the base of the Chantransial filaments, while that from the more northerly counties shows them more often above the base. This latter condition is particularly pronounced in collections from Bartholomew county and from Cataract Falls in Owen county.

Habitat. At all of the 81 stations where Lemanea has been found in Indiana, the stream beds have been composed either of solid rock or of rock fragments sufficiently large to prevent them from being readily moved by the rapidly flowing water. The size of the stream varies from large to rather small, shallow streams found in several of the counties. Invariably the alga grows where the flow of water is swift and where the stream is comparatively shallow. At Becks Mill, Washington county, the alga grows attached to the top of an iron pipe continually wet by the spray, as well as on the rocks in the stream bed nearby.

DISTRIBUTION OF LEMANEA IN RELATION TO GEOLOGICAL FORMATIONS IN SOUTHERN INDIANA

The large number of stations for Lemanea in Indiana has made it possible to consider the distribution of the genus in relation to the geological character of the substratum. Lemanea requires a comparatively uncommon habitat with a hard substratum, a swift current of water, and in most cases, a stream with a continuous flow of water throughout the year. The northern half of the state is covered with a deep layer of glacial drift, and consequently, there are few areas where water flowing swiftly over bedrock can be found. Lemanea is apparently absent from all of the northern half of Indiana.

In the southern half of the state, the glacial drift either is absent or forms only a thin layer, which many of the streams have cut through. Much bedrock is, therefore, exposed and there are numerous rapids and small waterfalls present along the courses of the streams. Several geological formations are exposed in this part of the state. On the eastern boundary is the Ordovician. Going westward, the other formations encountered are the Silurian, Devonian, Mississippian and Pennsylvanian. Some of these are composed principally of limestones and shales while others contain sandstones, conglomerates and coal seams. Limestones are very abundant in the Ordovician, Silurian, lower Devonian and upper Mississip-

pian formations. The upper Mississippian includes the Harrods-burg, Salem, Mitchell and Chester series. The upper Devonian is primarily shale while the lower Mississippian, which is known as the Borden or "Knobstone" series, is composed of sandstones and shales and only a small amount of limestone. The Pennsylvanian forma-tion is primarily one of coal, intermixed with sandstones, shales, con-glomerates and some-limestones.

Streams with rapids and solid rock beds are found on all of the geological formations although they are more common on the lime-stones. For several years a search has been made in the southern half of Indiana for all possible locations where Lemanea might be growing. Of the 81 locations found, all are in hard limestone re-gions. There are 58 of these on the Silurian and lower Devonian formations in the eastern half of southern Indiana and 23 on the upper Mississippian formation in the western half (map 1). Lemanea is absent from the upper Devonian and the Pennsylvanian formations, and except for their extreme western borders, is absent from the Ordovician and the Borden formations.

A few of the stations listed above are actually just beyond the eastern borders of the Silurian and the upper Mississippian forma-tions but the streams in which these stations are located have their origins in the formations where the other stations are found.

Thus the alga in Indiana is limited in habitat to regions of certain hard limestones in or bordering on the Silurian, lower Devonian and upper Mississippian formations. It is not found on most of the limestones of the Ordovician, Borden and Pennsylvanian formations. It is not found on the sandstones, coals, conglomerates and shales of any of the formations.

It would appear that the rock formations stimulate or prevent the growth of Lemanea by influencing the physical and chemical nature of the water in the streams. The relations between the alga and the geological formations would, therefore, be an indirect one. This is indicated by the fact that on these formations, but not elsewhere, Lemanea has been found growing on soil, iron piping and shell.

The reasons for the alga being limited to certain geological for-mations are not yet understood. It does not grow in the rapids of all rockbottom streams, even when the rock is limestone, as is indi-cated by its absence from all except the extreme western border of the Ordovician formation. No trace of Lemanea has been found in

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Switzerland, Ohio and Dearborn counties nor in the eastern part of Franklin county, although there are many places in these counties where water flows swiftly over Ordovician limestone.

The limited distribution may possibly be due to the presence or absence of small amounts of certain chemicals, such as magnesium, sodium or silica, which would vary in amount in the water according to the composition of the rock over which the stream flows. Rosenberg (15) has claimed that in the germination of spores of Lemanea in artificial culture media, certain precautions must be taken to ensure successful growth. He found that purity of the medium both in the chemicals and the distilled water used, the constitution of the glassware, and the effects of temperature and light are of chief importance. This sensitivity of the spores to chemicals would in itself be sufficient to limit the distribution of the alga in nature.

Relation of Lemanea in Indiana to Geological Formations

Each dot represents a location for Lemanea
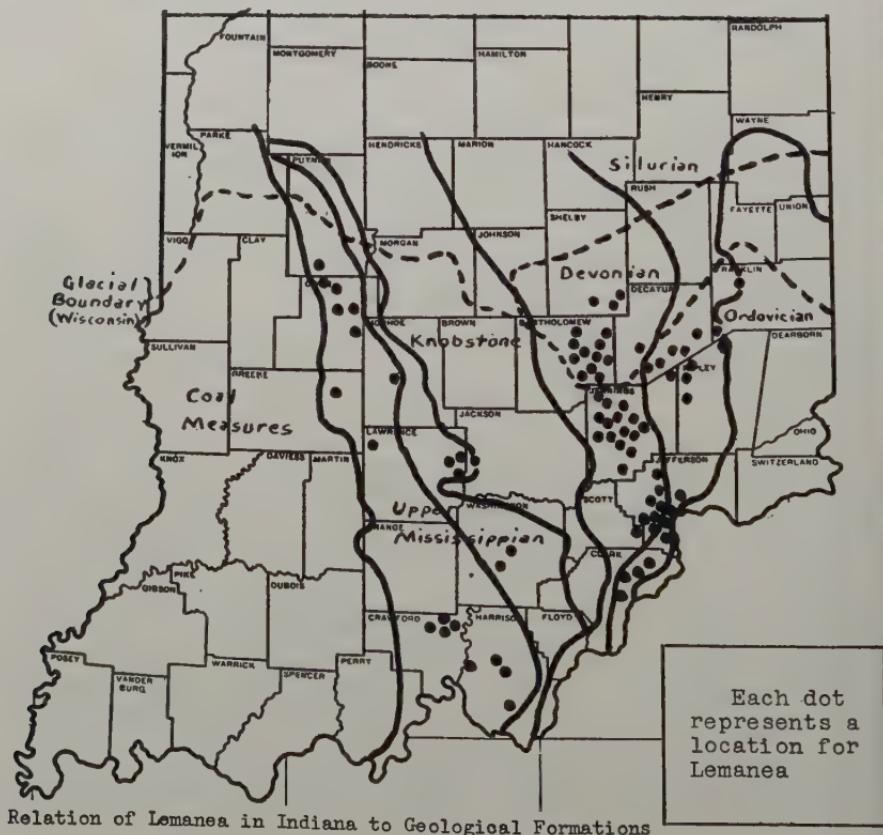
A study of the geological map of Indiana indicates the possibility that Lemanea may eventually be found in several additional counties where the Silurian, lower Devonian and upper Mississippian formations are exposed. These include southeastern Wayne, northeastern Union, western Fayette, southern Rush, western Morgan and east-central Parke counties. It does not seem probable that the Indiana types of the genus will be found in northern Indiana, western Ohio or eastern Illinois, for in these areas, the proper geological formations are not exposed to the surface. However, in Kentucky and Tennessee, extensive exposures of the Silurian, Dvonian and upper Mississippian are present, and the Indiana types of Lemanea will, in all probability, be found. In fact, three stations, one in Tennessee and two in Kentucky, have already been located, and they appear to be situated on hard limestones which belong to the same geological formations as those which support Lemanea in Indiana.

Other stations for Lemanea have been found in Kentucky on rocks of the Ordovician and the Pennsylvanian formations, but in every case, the plants belong to other species of the genus and are not of the Indiana types.

Eventually, if a large number of stations for Lemanea can be found in Kentucky, the relationship of various species and types of the genus to geological formations will be well tested in that state.

DISTRIBUTION OF LEMANEA IN NORTH AMERICA

A considerable number of recent collections of Lemanea from North America have been made available to the writer for study and identification, and it is found that they extend the known range of distribution, particularly of the subgenus Sacheria. The new records, together with those of Atkinson, Gordon, McInteer, Palmer, Smith and Wolle have been referred to in determining the distribution of the genus. The two subgenera, Sacheria and Eulemanea, are considered separately. However, the distribution of the individual species is not emphasized due to the taxonomic confusion among them which at present exists.

In the eastern part of the continent, Sacheria is distributed from Mississippi north through the Appalachian region into New York and New England, where a western arm extends through Ontario into Minnesota and a northeastern arm passes through New Brunswick into Nova Scotia and Newfoundland (map 2). Besides the

Canadian provinces mentioned above, the states involved are Minnesota, Maine, New Hampshire, Vermor .. Massachusetts, Connecticut, New York, Ohio, Pennsylvania, New Jersey (19), Maryland, Virginia, West Virginia, Kentucky, Tennessee, North Carolina, South Carolina, Alabama (19), Mississippi and Missouri (14). Ex-

Key:
● Old locations
✗ New locations
⊙✗ Locations
  indefinite

Distribution of the Subgenus Sacheria in North America

Key:
● Old locations
✗ New locations
⊙✗ Locations
  indefinite

Distribution of the Subgenus Sulemanea in North America
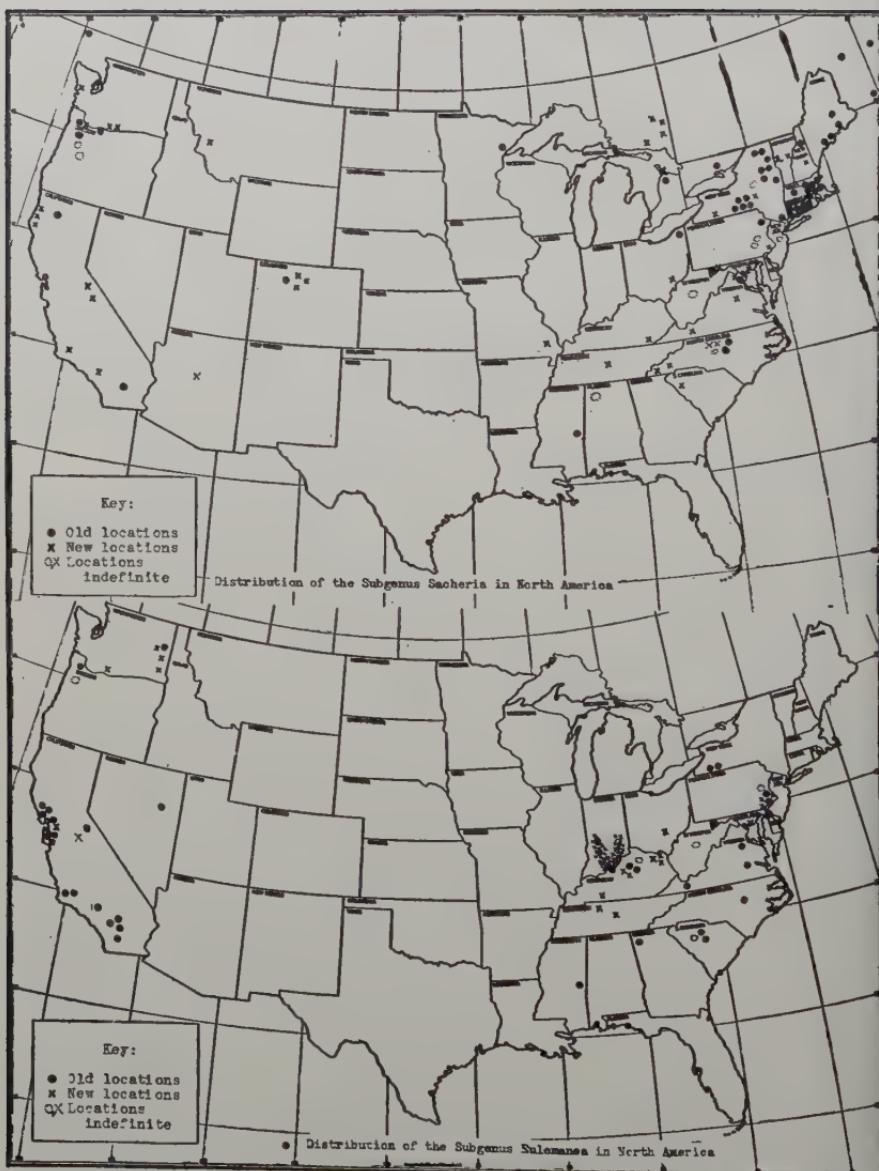
cepting for the arm extending into western Ontario and Minnesota, it is to be seen that the distribution of Sacheria is restricted to the general Appalachian Mountain region and that it is absent from the Atlantic coastal plain and the north central deciduous forest area south of the Great Lakes. Its distribution appears to be much the same as that for the eastern coniferous forest in Canada and the United States.

In western North America, the stations for Sacheria roughly form a "C" and are located in Montana, British Columbia, Washington, Oregon, California, Arizona and Colorado (map 2). It would seem probable that future collections from the west will show the entire Rocky Mountain region to be included in the area of distribution of Sacheria.

The distribution of the subgenus Eulemanea in eastern North America is much more restricted than that of Sacheria since it does not extend into New England and Canada. However, it does extend west from the Appalachian Mountain region into central Kentucky and southern Indiana. Its northern limit is in southwestern New York and it extends through Pennsylvania, Delaware, Maryland, Virginia, West Virginia, North Carolina, South Carolina, Georgia, Mississippi, Tennessee, Kentucky and Indiana (map 3). The fact that Eulemanea is recorded for Delaware on the east and Indiana on the west, indicates that this subgenus is not so closely restricted to the mountain region as is Sacheria.

Unlike Sacheria, Eulemanea in eastern North America is divided into several species. *L. grandis* has been reported for New York, Pennsylvania and Delaware and thus covers the northern port of the range for the subgenus. *L. torulosa* has been listed for Pennsylvania, Virginia and Kentucky, and specimens from Maryland recently obtained might also be included in this species. *L. australis* is primarily a species of the southern states and has been reported for Mississippi, Georgia, South Carolina, North Carolina, West Virginia and Maryland. Recent collections from Pennsylvania and Tennessee appear also to belong to this species. *L. pleocarpa* is reported for Kentucky and Virginia only. In Indiana all but four of the stations harbor the "Becks Mill" type of Lemanea; the other four, located in Jackson and Lawrence counties, are the sole locations for the "Jackson" type. There are two collections from Kentucky and one from Tennessee which belong to the "Becks Mill" type.

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The geographic distribution of each species of Eulemanea in the east is of little significance, however, until the validity of the species concerned can be determined by a study of a large number of additional collections made from all of the states in the same manner in which material from Indiana has been studied. All too frequently, specimens have been assigned to a species due primarily to their proximity to other stations for that species. Of particular interest in the distribution of the subgenus is the spur which extends from the south through Kentucky and into Indiana. This area is free of Sacheria and the only Lemanea which is common here is the "Becks Mill" type. The sexual shoots of this type are larger in diameter and in length than those of the other species found.

In Kentucky four Lemaneas are present. The "Becks Mill" type is limited to the same limestone formations on which it is found in Indiana; *L. torulosa* and *L. pleocarpa* are in the Ordovician region, while the one station for *L. fucina* is on shale in the southeastern Coal Measures area.

Eulemanea in western North America is limited in its present known distribution to Washington, Oregon, California, Nevada and one station in Mexico (map 3). Three species are represented; *L. mexicana* is the name given to the one collection from Mexico; *L. catenata* has four stations in California; *L. annulata* is recorded for all four states with several stations in California. As in the east, the distribution of Eulemanea overlaps that of Sacheria but extends farther south, while Sacheria extends farther north than the range common to both. Sacheria is also found in Montana, Colorado and Arizona where there are no records for Eulemanea and the latter is the only subgenus so far recorded for Nevada. Due to the comparatively few collections yet made in western North America, the recorded differences in distribution of the two subgenera there may be of little signiifcance.

SUMMARY

More than three hundred collections of Lemanea, approximately half of which are from Indiana, have been studied with particular emphasis on the characters of taxonomic importance. Characters previously much emphasized in distinguishing between species are found to vary within wide ranges. This variation is particularly evi-

dent in the material from Indiana, which shows this tendency in size, surface form, width of antheridial ring, location of cystocarps, size of spores and origin of sexual shoots.

The Lemanea collected in Indiana is distinct from that found previously in other states of eastern North America. With few exceptions, it is comparatively large in size, and during the most active stage of growth the color of the sexual shoot is green-violet while the antheridial rings are lighter in color and tend to be white to yellow, changing later to brown. The rings vary in width from narrow to very wide and commonly have an irregular margin. The surface form of the sexual shoot, while most often medium-undulate, is quite variable, ranging from shallowly undulate to prominently "dumb-bell-shaped" with gnarled nodes. The base of the shoot is gradually attenuate and not stipitate. Branching of the shoot is occasionally observed. The wall has a leathery texture, is frequently slimy when young, and is composed of cells which are compactly arranged.

The Indiana Lemanea has cystocarps which are generally limited to the internodes but may occasionally be present also in the nodes. Carpospores become mature during the late spring and early summer and are found in abundance. Their shape and size are quite variable. Many of the spores germinate during the fall while still within the sexual shoots. In the Chantransia stage the filamentous growth is abundant, up to 4 mm high, green or violet in color, and with branches which are often unilateral near the tip. There is a gradual decrease in their diameter from the base to the tip. The sexual shoots are developed from various locations on the filaments.

There are few new characteristics in Indiana Lemanea but the combination of characters which it shows is unique. It resembles *L. nodosa* and *L. catenata* in the green-violet color, large size, leathery texture and undulating to "dumb-bell-shaped" surface form of the sexual shoot. It resembles *L. annulata* in the white to yellow color of the antheridial rings. It conforms to *L. pleocarpa* in its occasional development of cystocarps in both nodes and internodes, and to *L. grandis* in the occasional production of very large spores. Finally, some Lemanea from Indiana resembles *L. torulosa* in its small size and the almost plane surface form of the sexual shoot.

The Indiana material is in most cases readily distinguished from the other Eulemaneas growing in eastern North America since the

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latter are almost always small in size, with less prominent nodes, and with dark-colored antheridial rings.

While Indiana material is similar to the most common western American species, *L. annulata,* in the light color of the antheridial ring and in the large size of the shoot, it lacks the delicate wall, and the very long and regular undulations of the sexual shoot, the regular margins and uniformly broad width of the antheridial rings, and the small clusters of sexual shoots which are important characters of *L. annulata.* Atkinson's (3) final decision placing the Indiana material in this species is, therefore, not acceptable.

Although resembling the European *L. catenata* more closely than any other species, the Indiana Lemanea differs in having light colored antheridial rings which vary in width and frequently are very wide.

All specimens of Lemanea from Indiana collected so far are here grouped as two related types, designated as "Becks Mill" and "Jackson." The former, which is the more common, is large in size and resembles the European species, *L. catenata,* in its leathery texture, violet color, prominent nodes, occasional branching of the sexual shoot, and the unilateral, top-heavy branching of the Chantransial filaments. The Jackson type is dwarf and early maturing and resembles *L. torulosa* in the smaller size and in the slightly undulate surface form. Both types resemble *L. annulata* in the light color of the young antheridial rings.

Variation and intergradation of taxonomic characters occurs not only in the Indiana Lemanea but also in the specimens from eastern and southeastern United States. This suggests that some of the species distinctions previously drawn may be untenable.

Eighty-one locations have been found for Lemanea in Indiana. These are restricted to hard limestone regions belonging principally to the Silurian, lower Devonian, and upper Mississippian formations. The Indiana types of Lemanea do not grow on other limestones, on shales, sandstones nor in areas of deep glacial drift.

Many new collections of the several species of Lemanea have made it possible to trace the distribution of its two subgenera in eastern and western North America. The subgenus Sacheria extends farther north than does the subgenus Eulemanea. Sacheria is now reported for twenty-six states in the United States and five Canadian provinces. Eulemanea is reported for seventeen states and one locality in Mexico.

ACKNOWLEDGEMENTS

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QUANTITATIVE STUDY OF THE PHYTOPLANK-
TON OF LAKE MICHIGAN AT EVANSTON,
ILLINOIS[1]

By Kenneth E. Damann

Beginning May 9, 1937, and continuing to May 3, 1938, Daily made regular weekly quantitative collections of the phytoplankton of Lake Michigan at Evanston, Illinois. Several ecological factors were studied in relation to their effect on the periodicity of the phytoplankton. However, due to the various fluctuations of physical and chemical factors, the data for any one year scarcely represent, in themselves, a complete picture of either the phytoplankton crop or its periodicity. It was therefore deemed advisable to continue the initiated quantitative survey over a longer period. At this point, December 1939, two years of collecting have been completed and an attempt has been made to summarize and compare the data for that period.

Although several papers have been published on the plankton of Lake Michigan, none has dealt with quantitative collections over any extended period of time. Briggs (1872) listed 45 species of diatoms found in Lake Michigan. Thomas and Chase (1887) brought together a long list of 215 species of diatoms found over a period of 16 years in the water supply of the city of Chicago. Ward (1896) worked in the Traverse Bay Region on the relation of plankton and bottom organisms to the whitefish. Jennings, Thompson and Kofoid later added appendices, on rotifers, phytoplankton, and protozoa respectively to Ward's publication.

Eddy (1927) published quantitative data obtained from two series of collections which were taken from November 1887 through October 1888 and in October 1926 and May 1927 at various points along Lake Michigan, mostly in the immediate vicinity of Chicago. A total of 119 species were found, sixty of which were phytoplankters and fifty-nine were zooplankters. A comparison of the more recent collections with those made forty years previous, showed that very

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little change had occurred in the general composition of the plankton. Diatoms were found to predominate at all times and constituted the majority of the organisms of the plankton.

Bayliss and Gerstein (1929) in a two year study of the phytoplankton and zookplankton in the lake water of the Chicago water supply found that peaks of plankton abundance were reached in May and October of 1927 but only in September of 1928. The writer is at present working on continuous monthly plankton records beginning in 1926 which were made available by A. E. Gorman and H. H. Gerstein of the Water Purification Department of Chicago, Illinois. It is hoped that such records will give us a more complete picture of phytoplankton periodicity and possibly suggest clues as to its explanation.

Both Eddy (1930) and Roach (1932) report a direct correlation of plankton abundance with temperature. However, Pearsall (1923) fails to stress temperature as a leading role in diatom periodicity, but is inclined to believe that the deficiencies of oxygen, nitrates, silica and calcium are usually limiting factors. In 1932, Pearsall takes a more definite stand when he writes that diatoms occur in winter and spring when nitrates, phosphates, and silica are in abundance, and that green algae occur in the summer when nitrates and phosphates are low.

Ahlstrom (1936) published a very complete account of the deep water and inshore plankton of Lake Michigan as disclosed in 115 samples taken during 1930 and 1931 by the United States Bureau of Fisheries from stations scattered well over the entire area of the lake. The inshore collections were made at Evanston, Illinois, between October 3, 1931 and June 20, 1932. He recognized the need for quantitative studies to establish the existence of seasonal periodicity which he detected in the qualitative collections.

Daily (1937) initiated this quantitative study of the phytoplankton of Lake Michigan at Evanston, Illinois. He considered temperature as being important in optimum growth but not significant enough to be the controlling factor of periodicity. Further correlations were made with hours of sunlight, turbidity, hydrogen ion concentration, and bacteria.

METHODS AND MATERIALS

During the two years of this phytoplankton study thus far completed, regular weekly quantitative collections were made from a breakwater adjoining the Northwestern University campus. The Sedgwick-Rafter method was used exclusively. This method consists of filtering water samples through sand supported upon 200 mesh bolting cloth disks and then calculating the number of organisms from the concentrate. The formula for such calculation is found in the Standard Method of Water Analysis, 1936 and is represented as follows:

$$\frac{\text{No. of fields in a 1 ml counting cell 1 mm deep}}{\text{No. of fields counted}} \ \text{X} \ \frac{\text{ml of concentrate}}{\text{ml of water filtered}} = \text{the multiplier}$$

The Whipple ocular micrometer was calibrated so that with a 10X ocular any observed field of the counting chamber was exactly equal to one square millimeter. One liter of lake water was concentrated to 10 cc and of the one cc of concentrate placed in the counting cell, ten fields were counted.

Thus:

$$\frac{1000}{10} \ \text{X} \ \frac{10}{1000} = 1$$

RESULTS

Quantitative collections of the phytoplankton of Lake Michigan from November 1, 1938 to November 1, 1939 yielded genera representing 5 classes of algae. Bacillariophyceae dominated every collection, averaging 94% of the total yield. Chrysophyceae, Myxophyceae, and Chlorophyceae were never very abundant. They yielded only 3%, 2% and 1% respectively while Dinophyceae yielded only a small fraction of 1% of the total phytoplankton for the year. The complete data on the occurrence of the various classes of phytoplankton are represented in table I. The environmental factors, sunshine and water temperature, are summarizd in table II.

A maximum yield of 1052 organisms per cc occurred May 9, 1939 while the minimum of 81 cc occurred twice, March 14 and 21, 1939. The maximum and minimum monthly averages were established during June and March respectively. Weekly collections of phytoplankton, when plotted in graph form, gave a very rugged curve and it was difficult to attribute causes to such sudden changes in yield. However, it might be noted that even though the maximum yield per cc occurred in May, the highest monthly average was recorded in June. The greatest weekly change in yield occurred between the last two weeks of July when the quantity of phytoplankton increased from 223 to 704 plankters per cc. Fragilaria, Tabellaria, Cyclotella, and Dinobryon were responsible for the sudden increase. Similar increases occurred in April and May but were due mainly to Synedra.

TABLE I

Monthly averages of algal classes expressed in numbers per cc and percentage of the total yield of phytoplankton.

	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Totals
Bacillariophyceae—													
Percentage	95.9	95.8	93.8	97.1	97.8	98.8	97.5	89.2	90.2	90.3	91.0	94.0	94 %
Per cc	403	364	272	134	94	266	631	612	388	328	267	366	343
Chrysophyceae—													
Percentage	1.5	1.8	3.1	0	0.1	0.4	0.5	4.5	7.0	6.6	5.4	1.4	3 %
Per cc	6	7	9	0	1	1	3	31	30	24	16	5	11
Myxophyceae—													
Percentage	1.9	1.8	1.7	2.2	0.1	0.4	0.8	4.2	1.0	1.1	2.0	2.3	2 %
Per cc	8	7	5	3	1	1	5	29	4	4	6	9	6.8
Chlorophyceae—													
Percentage	0.7	0.6	1.4	0.7	0	0.4	1.2	2.1	1.6	1.7	1.3	2.3	1 %
Per cc	3	2	4	1	0	1	8	15	7	6	4	9	5
Dinophyceae—													
Percentage	0	0	0	0	0	0	0	0	0.2	0.3	0.3	0	.06%
Per cc	0	0	0	0	0	0	0	0	1	1	1	0	.2
Total per cc	420	380	290	138	96	269	647	687	430	363	294	389	366

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TABLE II

ENVIRONMENTAL FACTORS

Months	Hours of sunshine	Average water temperature
November, 1938	197.3	7.6° Centigrade
December, 1938	114.3	1.5° "
January, 1939	85.5	1.2° "
February, 1939	160.3	0.6° "
March, 1939	240.7	3.3° "
April, 1939	211.3	7.5° "
May, 1939	347.7	12.2° "
June, 1939	313.2	17.5° "
July, 1939	358.2	19.7° "
August, 1939	337.7	21.1° "
September, 1939	301.5	18.1° "
October, 1939	233.4	11.4° "

BACILLARIOPHYCEAE

Diatoms are by far the most abundant plankton organisms of Lake Michigan. In April, 98.8% of the total phytoplankton was diatoms while 89.2% was the lowest record for the year and occurred in June when Myxophyceae, Chlorophyceae, and Chrysophyceae were at their maximum. The yearly average for diatoms was 94% of the total phytoplankton. The close parallelism between the yield of diatoms and the total phytoplankton (fig. 1) is broken only in June when the classes mentioned above were at their peaks.

The constituent genera of diatoms and the relative abundance of the dominant genera (table III) in numerical order is as follows:

1. Synedra was usually abundant in every collection. It ranged from 65% of the total diatom yield in May to 17% in December. Most abundant in May after which it decreases until September and then established a minor peak in October. The average yield for the year was 39% of the total diatoms.

2. Fragilaria was rather abundant throughout the year ranging from 5% in May to 28% in July. The average yield for the year was 17% of all the diatoms.

3. Tabellaria occurred rather uniformly throughout the year ranging from 3% in May to 21% in July. The average yield for the year being 11% of total diatoms.

4.   Cyclotella was similar to Tabellaria ranging from 3% in March to 24% in April; average yearly yield was 11% of the total diatoms.

Figure 1
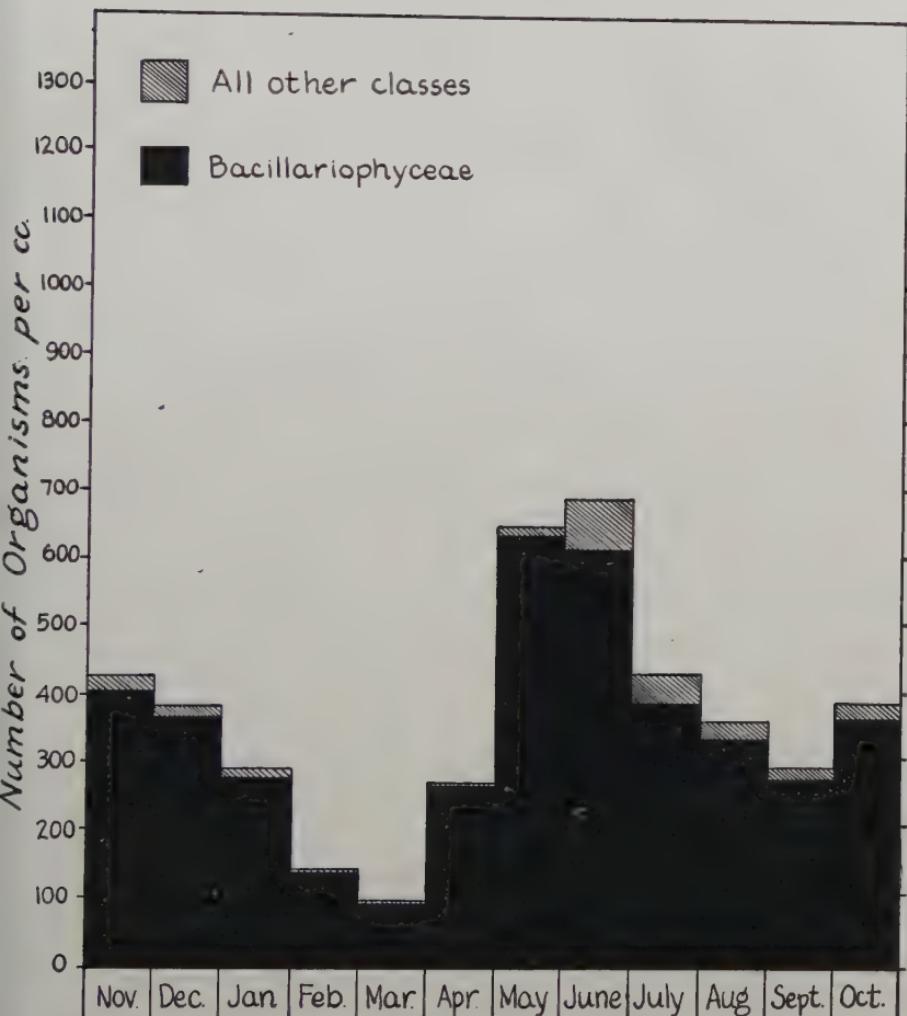
5.   Asterionella was present in all collections ranging from 1% in August to 20% in November. It was dominant in November and December and average 7% of total diatoms of the year.

6.   Navicula was present in all collections but never abundant. The September yield was 15% of the diatoms while the minimum was

less than 1% in April. The yearly average was 6% of the total diatom yield.

7. Melosira occurred the year around. It ranged from less than 1% in December to 17% in March with an average of 5% of all the diatoms for the year.

8. Nitzschia was present in nearly all of the collections but never abundant. It averaged 2% of total diatom yield.

9. Rhizosolenia was abundant only in May but was present in small quantities during the entire year.

10. Stephanodiscus was not present in all collections but occurred most frequently from May through October.

11. Cymatopleura and Amphiprora were equally abundant occupying .02% of the total diatom yield. The former was present every month with the exception of November and March. The latter was most abundant from May through September.

12. Cymbella and Pinnularia were never abundant and occurred less frequently than the two genera mentioned above.

13. Pleurosigma was reported in December collections but never with a significant number to yield more than .01% of the total diatoms for that month.

TABLE III

Bacillariophyceae—Monthly averages expressed in numbers per cc and percent of the total yield.

	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Yearly Average	
Amphiprora—	0.2	0.01	0.0	0.0	0.0	0.0	0.006	0.6	0.5	0.06	0.07	0.0	0.02	Percent
	1.	0.5	0.0	0.0	0.0	0.0	0.4	4.0	2.0	0.2	0.2	0.0	0.7	Per cc
Asterionella—	20.0	19.0	8.4	3.0	5.3	5.4	5.5	2.0	2.0	1.0	2.0	4.0	7.0	Percent
	82.0	68.0	23.0	3.6	5.0	14.5	35.0	12.0	8.0	5.0	4.0	13.0	22.7	Per cc
Cymbella—	0.2	0.0	0.0	0.01	1.0	0.02	0.003	0.003	0.02	0.3	0.7	0.2	0.01	Percent
	1.0	0.0	0.0	0.2	1.0	0.7	0.2	0.2	0.7	1.0	2.0	1.0	0.6	Per cc
Cymatopleura—	0.0	0.008	0.01	0.04	0.0	0.01	0.3	0.4	0.01	0.01	0.4	0.04	0.02	Percent
	0.0	0.3	0.5	0.6	0.0	0.5	2.0	3.0	0.5	0.4	1.2	0.2	0.7	Per cc
Cyclotella—	18.0	15.0	11.4	10.0	3.0	24.4	8.0	5.0	7.9	19.0	11.0	6.0	11.0	Percent
	73.0	52.0	31.0	14.0	3.0	65.0	50.0	29.0	31.0	62.0	29.0	22.0	38.4	Per cc
Fragilaria—	16.0	22.0	21.0	14.0	12.0	5.2	5.0	27.0	28.0	14.0	11.0	16.0	17.0	Percent
	63.0	80.0	58.0	19.0	11.0	14.0	30.0	164.0	109.0	47.0	30.0	58.0	56.9	Per cc
Melosira—	1.4	0.08	1.4	5.0	17.0	15.0	7.0	6.0	2.3	2.0	3.0	5.0	5.0	Percent
	6.0	3.0	4.0	7.0	16.0	40.0	43.0	34.0	9.0	6.0	7.0	19.0	16.1	Per cc
Navicula—	6.0	6.0	5.0	8.0	3.0	0.4	2.0	6.0	6.1	6.0	15.0	7.0	6.0	Percent
	24.0	22.0	13.0	10.0	3.0	1.0	13.0	36.0	24.0	19.0	41.0	26.0	19.3	Per cc

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TABLE III—(Continued)

Bacillariophyceae—Monthly average expressed in numbers per cc and percent of the total yield

	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Yearly Average	
Stephanodiscus—	0.0	0.01	0.01	0.0	0.0	0.0	0.4	0.4	0.5	0.6	0.01	0.8	0.3	Percent
	0.0	0.7	0.5	0.0	0.0	0.0	3.0	3.0	2.0	2.0	0.5	3.0	1.2	Per cc
Synedra—	22.0	17.0	29.0	45.0	46.0	41.0	65.0	38.0	29.3	34.0	45.0	51.0	39.0	Percent
	87.0	62.0	79.0	60.0	43.0	108.0	412.0	234.0	114.0	111.0	121.0	187.0	134.8	Per cc
Tabellaria—	14.0	14.0	18.0	11.0	9.0	6.0	3.0	9.0	21.1	20.0	10.0	9.0	11.0	Percent
	56.0	51.0	50.0	15.0	8.5	15.0	17.0	57.0	82.0	66.0	26.0	34.0	39.7	Per cc
Rhizosolenia—	0.2	1.0	2.0	0.04	0.5	0.02	0.9	3.0	0.2	2.0	0.7	0.1	1.0	Percent
	1.0	6.0	5.0	0.6	0.5	0.7	6.0	17.0	1.0	4.4	2.0	0.6	3.7	Per cc
Nitzschia—	2.0	5.0	3.0	3.0	3.0	2.2	3.0	3.0	0.8	1.0	0.7	0.2	2.0	Percent
	9.0	18.0	8.0	4.0	3.0	6.0	19.0	18.0	3.0	4.0	2.0	0.8	7.9	Per cc
Pinnularia—	0.0	0.0	0.0	0.0	0.0	0.01	0.008	0.1	0.5	0.0	0.4	0.3	0.001	Percent
	0.0	0.0	0.0	0.0	0.0	0.5	0.6	1.0	2.0	0.0	1.0	1.2	0.05	Per cc
Pleurosigma—	0.0	0.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0001	Percent
	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.004	Per cc
Total...403	403	364	272	134	94	266	631	612	388	328	267	366	343+	

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CHRYSOPHYCEAE

The Chrysophyceae represented mainly by Dinobryon and Synura was present in all the months of the year with the exception of February. Dinobryon was most abundant from June to October. A major peak was reached in July when 7% of the monthly phytoplankton was Chrysophyceae. The average for the year was 3% of the total yield of phytoplankton. Observations indicate, on the basis of abundance in plankton tows, that Synura would have been more abundant in the quantitative collections had the colonies not been so easily disassociated in the filtration process.

MYXOPHYCEAE

The Myxophyceae were never abundant but were present every month of the year ranging from 0.1% in March to 4.2% in June. The average for the entire year was 2% of the total phytoplankton. These facts are interesting in comparison with the absolute autumnal dominance of blue greens in Lake Erie (Tiffany, 1938). It is possible that the greater depth of Lake Michigan and a lower maximum temperature do not permit such an autumnal development of blue greens. The filamentous forms were represented by Oscillatoria, Anabaena, and Lyngbya while the colonial members were mainly, Microcystis, Merismopedia, Chroococcus, and Coelosphaerium.

CHLOROPHYCEAE

The Chlorophyceae like the blue greens were never abundant but were present every month with the exception of March. In June, the maximum yield was reached with 15 organisms per cc which was the equivalent to 2% of the total monthly yield of phytoplankton. In July, August, September, and October, the greens were more abundant than in the winter and spring months. The class was represented mainly by Scenedesmus, Ankistrodesmus, Coelastrum, Pediastrum, Dictyosphaerium and Westella. The Chlorophyceae were responsible for 1% of the total yield of phytoplankton for the year.

DINOPHYCEAE

The Dinophyceae yield was never abundant and the only monthly records were July, August, and September. Ceratium was present

in July, and Peridinium in August and September. However, from the observations on plankton tows, it appeared that Ceratium was more abundant and present over a longer period of time than the quantitative collections revealed. The class was responsible for .06% of the total phytoplankton for the year.

COMPARISON OF THE 1937-38 AND THE 1938-39 DATA

In comparing the results of the quantitative study of the phytoplankton of Lake Michigan made by Daily from May, 1937 to May,

FIGURE 2
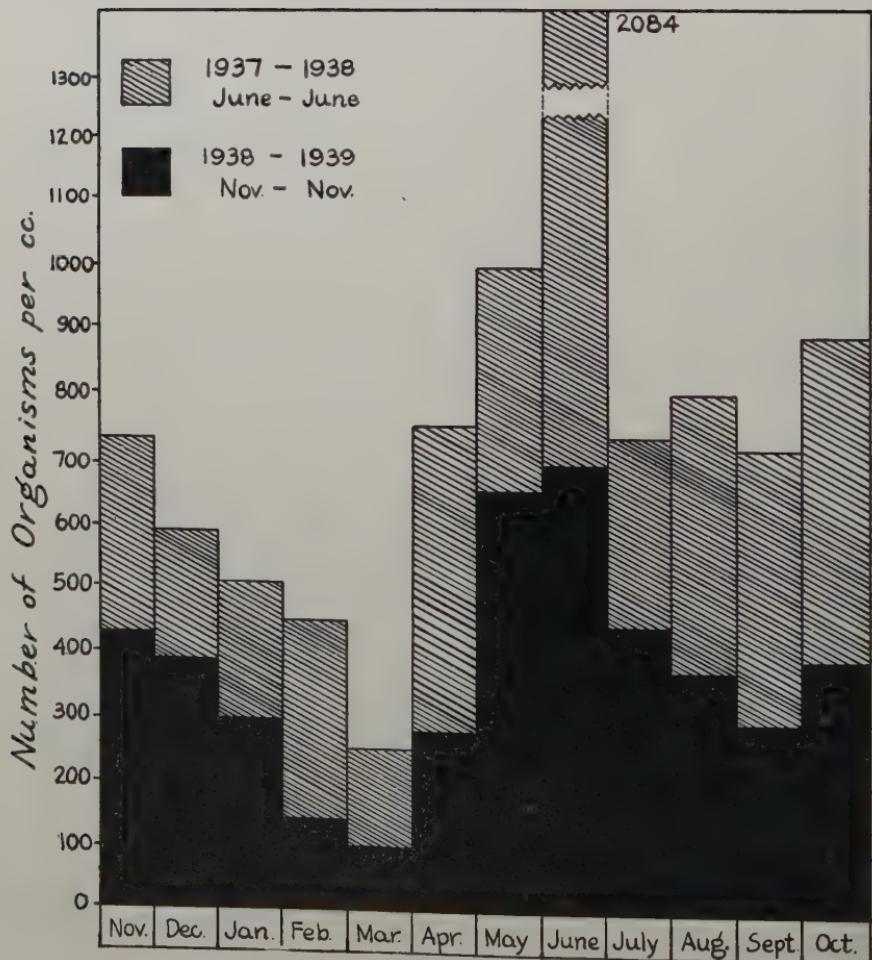
1938 with the present study which involved collections from November, 1938 to November, 1939, a close parallelism (fig. 2) was obtained. However, the consistently lower yield during 1938-39 presents a problem which allows for much speculation.

Regardless of the seemingly great difference in total yield of the phytoplankton, many of the conclusions drawn by Daily were definitely confirmed with the 1938-39 data. The total phytoplankton and the classes both revealed marked periodicity. The classes occupied the same order of numerical abundance (table I) with the Bacillariophyceae the most abundant followed by the Chrysophyceae, Myophyceae, Chlorophyceae, and Dinophyceae. The total phytoplankton showed considerable weekly variation and it exhibited a spring and autumn maximum. Both the 1937-38 and the 1938-39 maxima in monthly yields occurred in June while the minima occurred in March. The order Pennales led the Centrales in number and species at all times. The environmental factors, water temperature and hours of sunshine again showed a definite correlation to periodicity. The genera and species occurring during the 1938-39 study were essentially the same as those included in the Systematic List of Phytoplankton compiled by Daily.

The consistently lower yield for the entire year, 1938-39, prompted an investigation as to its possibilities. First, it is highly probable that 1938-39 could have been a "deficiency" year as far as the yield of phytoplankton is concerned. The environmental factors, chemical and physical, could have been operating in such a way as to prevent a yield comparable to that reported in 1937-38. The character of the graph (fig. 2) would tend to substantiate this claim but it also appears obvious that a consistent error in method might well be operating to produce such a relationship. However, if a counting error was operating, it would, out of necessity, be consistent throughout the study and could not be used in explaining the two major inconsistencies in yield occurring in June and August which are to be considered later. Close check was made with Daily's method of determining counting units and the same procedure was followed. He states: "In counting the organisms, each planktont, regardless of the number of component cells, was counted as a unit. Rhizosolenia, Scenedesmus, Dinobryon, filaments of Fragilaria, Tabelaria, and Melosira were respectively counted as units. Likewise, a single cell of a colony or filament was counted as a unit if

found separated from the original aggregate. As suggested by Todd and Sanford for blood corpuscle enumeration, cells which touched the lower and right sides of each square were counted as if within the squares."

As the possibility of an error in filtration and concentration appeared likely, water samples were taken over a period of fifteen consecutive days and concentrated in different ways by varying the amount of suction pressure to determine the effect it might have on numerical counts. Surprisingly, the amount of suction had little or no effect on the quantitative counts. Over a five-day period there were 7 more plankters per cc in the sample concentrated with a slow rate of suction. Even though the amount of suction apparently had little or no effect on the number of plankters per cc, it did not necessarily follow that organisms were not being lost by the use of suction in the process of concentration. Further study revealed that slightly more organisms were present when concentrated by the use of gravity only for pressure but the significant difference occurred when counts were made on an original cc of unconcentrated lake water and compared with a count derived after the lake water had been subjected to concentration by filtering through sand. A concentrated cc contained 314 plankters while the original unconcentrated cc of lake water contained 1452 plankters as an average per day over a five day period. However, more comparative counts will have to be made over a longer period of time before we can state the percentage of plankters lost by concentration.

Besides the low yield of 1938-39 another problem involves the explanation of the extremely high peak established in June, 1937-38 and the absence of such a peak in 1938-39. A sudden increase in yield during August was also evidenced in 1937-38 while in 1938-39, the yield for the same month showed a gradual decline over that of the preceding months. As the Bacillariophyceae was responsible for 94% of the total phytoplankton yield, it was by analyzing the yields of the various genera of diatoms that a partial explanation of the two conspicuous inconsistencies was derived. First, the exceptionally high increase of Synedra (fig. 3) from May to June of 1937-38 and a marked decline during June 1938-39 explain the largest variation in yield. A second but lesser peak of Synedra in August 1937-38 and no such occurrence in 1938-39 explain the other. The February, 1937-38 yield of Synedra failed to alter the consistent character of

the total phytoplankton curve (fig. 2). The abundance of Fragilaria during November, December, and January preceding February off-set such a possibility. From the evidence, now at hand, it appears that each genus has high and low productive years which in turn

FIGURE 3
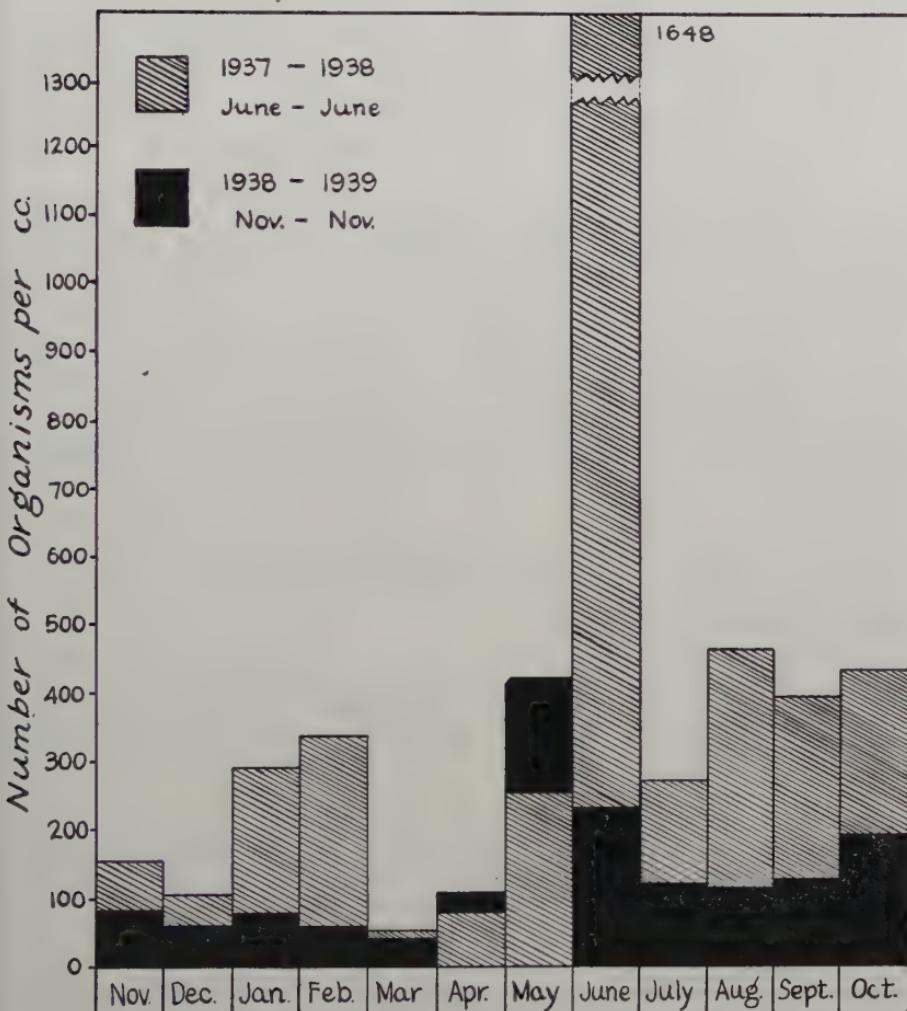
have a pronounced effect upon the total yield of phytoplankton for any one year. It is probable then, that such evidence would support the higher total yield of phytoplankton for 1937-38 as due mainly to Synedra. Bayliss and Gerstein (2) have records bearing out this

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assumption during 1927 and 1928 when Tabellaria was especially abundant during the first year and then the second followed as a very low productive year for the genus Tabellaria mainly. It would appear (fig. 3) that the Synedra yield of 1938-39 should have surpassed the 1937-38 yield according to its abundance during April and May. However, it is evident that something happened and instead of an expected increase in June there was a marked decline of Synedra. It is with the contributing factors to such a variation in yield that our problem is now centered.

SUMMARY AND CONCLUSIONS

1. The Bacillariophyceae dominated every collection, averaging 94% of the total phytoplankton. Chrysophyceae, Myxophyceae, and Chlorophyceae were responsible for 3%, 2% and 1% respectively, while Dinophyceae yielded only a small fraction of 1% (table I).

2. The maximum weekly yield of 1052 organisms per cubic centimeter was recorded May 9, 1939 while the minimum of 81 occurred twice, March 14 and 21, 1939. The maximum and minimum monthly totals (fig. 1) were established during June and March respectively.

3. Two peaks of abundance were evident in the average monthly totals of phytoplankton. The major peak occurred in June; the minor in November.

4. Each genus displayed its own pulse independently at sometime throughout the year. Asterionella and Cyclotella each reached a peak in November, Synedra in May, Fragilaria in June and Tabellaria in July.

5. The total Bacillariophyceae closely parallels the total phytoplankton except in June, when the Chrysophyceae, Myxophyceae, and Chlorophyceae reached their peaks (fig. 1).

6. Some of the constituent genera of diatoms and their relative abundance for the year are the following: Synedra, 39% ; Fragilaria, 17% ; Tabellaria, 11% ; Cyclotella, 11% ; Asterionella, 7% ; Navicula, 6% ; Melosira, 5% ; Nitzschia, 2% ; Rhizosolenia, 1% ; Stephanodiscus, 0.3%. Cymatopleura, Amphiprora, Cymbella, Pinnularia and Pleurosigma ranked in the order mentioned but with an almost insignificant yield.

7. The Chyrsophyceae represented mainly by Dinobryon and Synura were present in all monthly averages with the exception of February. The average for the year was 3% of the total phytoplankton.

8. The Myxophyceae were never abundant but were present every month of the year ; ranging from 0.1% in March to 4.2% in June. The average for the entire year was 2% of the total phytoplankton. Tiffany (1938) reported an absolute autumnal dominance of the Myxophyceae in Lake Erie but no such occurrence has yet been detected in Lake Michigan.

9. The Chlorophyceae, likewise, were never abundant but were present every month with the exception of March. They were responsible for 1% of the total phytoplankton.

10. The Dinophyceae, few in number and species, were present during three consecutive months only. Ceratium occurred in July and Peridinium in August and September. However, the plankton tow collections seem to indicate that the above mentioned forms were more abundant throughout the year.

11. Temperature apparently has a pronounced effect upon the total phytoplankton but is not the sole determining factor of periodicity.

12. Hours of sunshine show a positive correlation with the total phytoplankton during the spring and summer months but have little or no relation to the October increase.

13. A close parallelism was evident between the 1937-38 and the 1938-39 quantitative studies of the phytoplankton of Lake Michigan. However, a comparison of the total yield of phytoplankton (fig. 2) and the total yield of Synedra (fig. 3) reveals a partial explanation of the conspicuous inconsistencies, the 1937-38 June and August totals of phytoplankton. As a result, it becomes evident that the real explanation of the problem now lies in determining what factors might be responsible for the high and low productive years of the various genera and not alone determining what genera are responsible for the variations in yield from year to year.

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THE DIRECT MICROSCOPIC ANALYSIS OF MILK OVER A PERIOD OF ONE YEAR FROM THREE CREAMERIES SERVING INDIANAPOLIS

By GEORGE W. WADE

This study involves the agar plate count and the direct microscopic count of milk received from three sources, taken at weekly intervals, over a period of one year. It also includes recognition of the morphological types of bacteria found in milk, in an effort to determine the past history of the milks studied, and to determine the seasonal differences in the bacterial counts of this milk from each of the three sources.

Sedgwick and Batchelder (2) in the results of their bacteriological examination of Boston milk were among the earliest to bring to the public realization of the importance of dairy sanitation. The beginnings of certified milk in 1893 by Coit and Francisco (3) also involved the use of laboratory methods for controlling the number of bacteria present in milk and it was the city of Montclair, N. J., which first undertook regular bacteriological examinations of its milk supply. Probably the first work done on a state wide basis was that organized by Conn in Connecticut in 1908. The first committee of American Public Health Association was appointed in 1905 to standardize methods of control of milk. By the time the report was drawn up and adopted in 1910, 21 cities of the United States and Canada had adopted plans. In 1910 examinations in Baltimore, Philadelphia and Boston areas consisted of microscopic examination of centrifuge sediments for leucocytes and streptococci. In 1929-30, according to Standard Methods (1), 125 commercial laboratories analyzed more than 294,000 samples by the direct miscroscopic method in the United States and 2,500 samples in Canada.

The direct miscroscopic test first developed by Breed (1) has proved to be of immeasurable value on raw and pasteurized milk. It is the best means for determining the presence of excessive number of body cells in raw milk; it is a positive and reliable method for determining the typical intermingling of streptococci and cells in mastitis-infected milk; it also shows the presence of soil organisms, acid formers, colon and putrefactive types of bacteria.

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The United States Government has set up regular rules as to the most effective means of drawing and handling milk (6). Where these regulations have been in effect, they have been of great help in improving the quality of the milk. Since in Indianapolis these rules are not in effect. it was believed that the method of handling milk in this city would lead to great differences in the quality of milk from different dairies. This was found to be true in a previous study by Miss Stanley (5) in this laboratory.

The direct microscopic method is rarely used by dairymen on pasteurized milk, but in many cases forms part of the tests of raw milk as it enters the dairy. Since each type of organism is an indicator of the conditions under which the milk is produced and distributed, a microscopic study of the smear reveals a history of the milk. The diplococci, paired spherical bacteria, are normal flora of milk; these are known as lactic acid bacteria. These forms in excessive numbers indicates slow cooling. The short streptococci, single or paried spherical bacteria in chains of 3-6 cells, are also lactic acid bacteria and in excessive numbers are likewise indicators of slow cooling. Long chains of spherical streptococci together with an excessive number of body cells, i. e., over 3,000,000 per cc, indicate mastitis.

Staphylococci and paried bacilli are indicators of unclean utensils. They originate in unclean surfaces and moist residues remaining on the surfaces of the cans between milkings, and from the fat and casein residues found in crevices and open seams of utensils and cans. Their presence in large numbers is an indication of dirty milking machines and cans. Mold fragments are seldom observed in fresh milk (4) but are commonly found around farms, and in milk which has come into contact with some surface containing a scum of sour milk solids. Their presence in large numbers is an indication of dirty cans, milking machine tubes, and connections.

Rods in clumps, individual rods and amorphous matter are indicators of dust, dirt, feed and other kinds of external contamination. These may be seen as long, heavy rods in chains, or in clumps; as short blocky rods also in chains or in clumps; and as long thin rods in chains. The sources of these forms and the mold which often accompanies them, are the flanks and udder of the cow, dust and dandruff from the cow, feed, wet milking, water, manure, etc. These bacteria often include thermoduric and thermophilic types. Bacteria

of the former group are not destroyed by pasteurization and those of
the latter group grow abundantly at pasteurization temperatures.

PROCEDURE

Both agar and direct miscroscopic methods were used. In the
latter, the object was to examine for types and numbers of each type
of bacteria as well as total numbers. One pint bottle of milk, as
delivered to the homes of consumers was obtained from each of three
companies and taken to the laboratory for examination. This was
done on each Saturday from December 3, 1938 to November 11,
1939. Companies delivering the milk are unaware of this experiment
and are designated by the letters A, B and C.

The agar used for the plate method was prepared according to the
formula recommended in Standard Methods (1). Sterile plates,
agar and water blanks were used. The pipettes were kept in clean-
ing solution from one time of use until the next. Dilutions of 1:100
were found by experiment to be best and these dilutions were plated
and incubated at $37°$ C for 67 hours. For the direct method, 0.01 cc
of whole milk was taken in a calibrated pipette, deposited on a clean
slide, and spread over an area of one square centimeter with a sterile
needle. This was allowed to dry thoroughly, placed in xylol for five
minutes to remove the fat, dried again, and dipped into 95% alcohol
for five minutes to fix the material to the slide. After drying, the
slide was dipped into a saturated aqueous solution of methylene blue
for two to five seconds. Where necessary, the slide was destained in
95% alcohol.

A microscope with 15x ocular and 1.8 immersion oil objective was
used for counting the bacteria. The drawtube was adjusted to give
a field with a diameter of 0.146 mm making it possible to examine
1/600,000 part of a cubic centimeter of milk in each field. Thirty
fields of each sample were observed for the number of body cells,
bacterial clumps, diplococci, short streptococci (chains of eight or
less), long streptococci (chains of more than eight), staphylococci,
isolated cocci, isolated rods, rods in clumps, mold fragments, total
number of bacteria and number of groups of bacteria.

RESULTS

The numbers of body cells, clumps, diplococci, short and long
streptococci, staphylococci, isolated cocci, isolated rods, rods in

clumps, mold fragments, groups of bacteria and total bacteria per 30 fields are given in terms of monthly averages and seasonal averages in table I. In view of the dilutions and size of fields studied, each figure must be multiplied by 20,000 to secure the actual numbers per cc of original milk. Table II presents, in monthly and seasonal averages, a comparison of the counts by the plate and direct microscopic method.

Lactic acid bacteria and temperature. These organisms are diplococci and short streptococci. When large number of these bacteria are present it is conclusive evidence that the producer has failed to properly cool the milk, (4). The diplococci and the short streptococci followed the temperature curve except for Company A for the month of October, reaching an all time high of 2922 for the diplococci for 30 fields (1/20,000 cc). In short streptococci it was noticeable that Companies A and B kept their count down, with a low count of zero for Company A in November and of 5 for B in March and April. The lowest count of Company C was 12 for the month of February. When milk is cooled down to the optimum temperature for their growth (70° F) the streptococci have a tendency to become larger in size and arrange themselves in short chains. When milk is cooled carelessly (down to 80-85° F) these streptococci have a tendency toward a smaller size usually arranged in clumps which break up later to give the bacteria a scattered appearance. Poor cooling is a good explanation for the presence of excessive number of bacteria in the usual run of market milk (4).

Bacteria from unclean utensils. These organisms appear as isolated cocci, or as clumps of spherical bacteria (staphylococci), resembling bunches of grapes. Producers using milking machines which are not properly cleaned and sterilized are greatly troubled by this type of contamination. Staphylococci originate primarily from the fat and casein residues found in crevices and open seams of utensils and cans. They are abundantly found in dirty milk machines and cans (4). Except for an unexplained rise of Company A in January, the staphylococci followed the rise and fall of the temperature chart. All companies were high during the summer months, but Company C was very high, having twice the number of organisms per 30 fields as the second company. The all-time high here was Company C during months of June with 619; July with 635; August with 495; and September with 599. It is only during the

summer months that the staphylococci prove to be good indicators of dirty utensils.

Isolated cocci followed the chart of temperature except for the month of November when Company C rose to a high of 733 cells per 1/20,000 cc. This number (733) was the all-time high for the samples tested. Company C was high for six months; December with a count of 154; April, 43; May, 99; July, 613; August, 217; and November with 733. Company A had the lowest counts for the experiment with the following low counts per 1/20,000 cc: December, 42; May, 50; June, 83; August, 89; September, 63; and November, 48. Only in October with a count of 269 did this company (A) lead the other two companies. In interpreting the results we assume that the higher the staphylococci and isolated cocci count, the greater the lack of cleanliness of utensils. The companies are thus rated: cleanest, Company A; dirtiest, Company C; and medium, Company B.

Bacteria from dirt. Belonging to this group are bacteria associated with dust, dirt, feed, etc. These can be recognized as long, heavy rods in chains or clumps. They are also associated with the above types of bacteria. Company C was predominantly high in isolated rods, throughout the entire experiment, but there was a tendency to follow the temperature curve. Company B was down throughout; Company A rose through the months of April and August. Company C was up enormously high in clumps of rods for the entire experiment while Company B was down throughout, with Company A rising from April to September, inclusive.

Mold fragments followed the temperature curve in all three companies with none present for January, February and March for any company. During the summer months the number rose moderately. Mold probably had its source with dirt, but since the rise and fall of the number is closely related to the temperature curve, mold fragments are not good indicators of the amount of dirt present.

Many bacteria which gain entrance into the milk from the above named sources are of the thermoduric (heat-resisting) and thermophilic (heat-loving) types of organisms. In the former group, the bacteria are not destroyed by pasteurization, and in the latter group they grow abundantly at pasteurization temperatures.

Mastitis indicators. Body cells and long streptococci, when they appear together in large numbers, are indicators of mastitis. The

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high number of long streptococci and of body cells were found in Company C in March. High counts of long streptococci are found in December for Company C, in February for Company B, and in October for Company A, but these high counts are not accompanied by correspondingly high counts of body cells. With these exceptions, the long streptococci count tends to increase from winter to summer and to decrease again in the fall, indicating that many long streptococci may be lactic acid bacteria which increase with temperature rises. Body cells in all three companies followed the air temperature curve with very little fluctuation, except for the months of December and January where the counts rise to 61 and 75 for the respective months in Company C.

A high leucocyte count should not always be interpreted as mastitis. Cows giving colostrum milk and stripper cows will show a high leucocyte count. The same is true of cows whose udders become bruised during any time of their lactation period, or whose resistance have become weakened by over-feeding, etc. Except for a high leucocyte count in Company B in October, the number does not vary much during the year in any of the companies. It is not easy to detect the presence of mastitis in composite samples of milk as received by the consumer. Individual cases should be tested.

Relation of Plate count to the total microscopic count and total group count. The plate and microscopic count both gave only estimates of the total number of bacteria present, but the latter is more accurate. This is true because the plate method counts only colonies, each one of which may have started from any number of individual cells. The microscopic method is also quick. Only a few minutes are required in the latter method to determine with what kind of milk one is dealing. If the sample is not of high quality, the cause can be quickly determined and remedied. In order to learn anything from a plate count, two days must elapse for incubation, and by that time any undesirable milk which might be discovered will have been distributed to the consumer.

In all counts, the direct counts were much higher than the plate count, (table II) as would be expected. Not in all cases did the highest tally correspond in the same companies for the two methods, as in the plate count; Company A was high during the spring, summer and fall seasons, whereas the direct count was high only during the fall, dropping to the lowest of the three companies for each of the

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other three seasons. In each case, however, the counts rose in correlation with the rise of temperature.

The ratio of the plate counts to the group microscopic counts are as follows: Company A, 1 :150; Company B, 1 :500; and Company C, 1 :500. The ratio of the plate count to the individual microscopic counts are as follows: Company A, 1 :110; Company B, 1 :400; and Company C, 1 :425. The higher the ratio, the higher is the number of dead organisms present to the number of living organisms. This is shown in Company A which had a lower microscopic count and a higher plate count than Company C which indicated that the number of living bacteria was higher in Company A. The high microscopic count of Companies B and C indicated poor past history, but this was fairly well covered up in the results of the plate count by pasteurization.

CONCLUSIONS

1. For the lactic acid bacteria Companies A and B held the low position and Company C was high throughout the year. All these counts rose in warmer weather.

2. Indicators of unclean utensils placed the companies in the following order: first, Company A; second, Company B; with Company C, third. Indicators here were good only during the summer months.

3. The rating of the companies by bacteria from dirt was: Company C, highest count, hence most dirt; Company B, lowest count, hence the least dirt; with Company A occupying the medium position.

4. Mold was not a good indicator of dirt, since the rise in the number of these organisms followed a constant pattern. No mold appeared during the months with low air temperatures, and the numbers of mold fragments were nearly identical during the months when the air temperatures were high. In no case did the number of mold fragments correlate in its rise and fall with the number of isolated rods and rods in clumps.

5. It is hard (or impossible) to detect mastitis in composite samples. There is one possible exception to this and that was Company C during March.

6.   In the total counts the ratio of plate to direct microscopic count was lower in Company A and about equal in Companies B and C for both group and individual ratios.

7.   There was no doubt as to which company ranked lowest in sanitary quality since C kept that position almost consistently.   This milk evidently came from a dairy which was neglectful of sanitation in several respects.

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TABLE I

Number of organisms per 30 microscopic fields (1/20,000 cc of original milk) by direct microscopic count in terms of monthly and seasonal averages. First horizontal line for each month is Company A, the second line is B and the third is C.

Month	Body Cells	Clumps	Diplococci	Streptococci Short	Streptococci Long	Staphylococci	Isolated Cocci	Isolated Rods	Rods in Clumps	Mold Fragments	No. of groups of bacteria per 30 fields	No. bacteria per 30 fields
December	55	38	56	12	42	17	42	7	18	:	156	212
	59	29	28	31	31	36	43	3	6	:	180	189
	61	99	95	30	1106	44	154	9	768	:	2200	2300
January	53	27	23	35	49	547	39	5	12	:	294	326
	51	15	20	13	31	44	29	1	:	:	136	151
	75	57	43	35	31	43	28	9	290	:	480	612
February	49	11	10	13	10	13	52	4	5	:	97	109
	41	28	28	27	120	46	36	2	1	:	261	290
	61	34	27	12	17	126	38	7	59	:	311	325
March	41	77	115	43	41	94	44	11	12	2	381	462
	44	8	9	5	12	5	27	2	:	4	64	72
	71	69	46	43	226	87	23	17	248	5	694	738
April	43	42	41	26	16	26	37	27	80	8	250	293
	43	11	16	5	6	6	33	3	:	3	65	81
	46	38	34	35	:	17	43	18	277	5	351	380

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TABLE I—(Continued)

Number of organisms per 30 microscopic fields (1/20,000 cc of original milk) by direct microscopic count in terms of monthly and seasonal averages. First horizontal line for each month is Company A, the second line is B and the third is C.

Month	Body Cells	Clumps	Diplococci	Streptococci Short	Streptococci Long	Staphylococci	Isolated Cocci	Isolated Rods	Rods in Clumps	Mold Fragments	No. of groups of bacteria per 30 fields	No. bacteria per 30 fields
May	56	61	60	31	30	53	50	40	85	2	350	411
	41	46	45	24	34	108	50	4	4	3	279	340
	39	167	165	25	42	113	99	55	426	5	890	1055
June	49	160	182	44	73	194	83	22	42	8	693	854
	60	114	143	49	142	336	225	8	15	3	927	1034
	56	363	443	468	192	619	187	128	399	8	2102	2465
July	82	261	293	123	151	192	88	43	43	4	935	1156
	62	225	708	152	275	294	40	16	14	2	1760	1985
	69	565	600	218	218	635	613	583	593	5	3561	4125
August	86	230	354	106	106	164	86	20	16	4	854	1085
	68	231	345	130	203	137	179	10	20	3	1029	1205
	55	786	1103	185	555	495	217	476	546	3	4057	4718
September	72	123	269	58	39	105	63	7	25	4	526	669
	55	78	100	36	47	81	64	2	3	3	356	426
	45	511	500	144	175	599	84	447	965	5	2798	3308

October	66	1569	2922	312	332	166	269	5	11	:	3987	5553
	107	78	112	38	42	104	107	2	:	2	375	483
	35	117	171	67	56	109	66	170	846	4	1491	1690
November	51	27	84	:	:	135	48	8	2	1	133	260
	37	25	34	17	:	35	120	6	:	4	207	232
	24	116	64	26	16	79	733	38	286	:	1266	1372
Winter	52	25	29	20	33	195	44	5	11	:	182	215
	50	24	25	23	60	42	36	2	2	:	195	210
	64	63	53	25	384	71	73	8	372	:	997	1073
Spring	46	60	72	33	29	57	43	26	59	4	327	388
	42	21	26	11	17	39	36	3	1	3	136	164
	52	91	81	34	89	72	55	30	317	5	645	724
Summer	72	217	376	94	100	183	85	28	33	5	660	1031
	63	190	398	110	206	256	148	11	16	2	1238	1408
	60	571	715	290	321	583	339	395	512	5	3240	3769
Fall	63	573	1095	156	123	135	126	6	12	1	1548	2160
	66	57	82	30	29	73	97	3	1	3	312	380
	34	238	235	79	82	262	294	218	699	3	1851	2123

TABLE II

Comparison of plate and direct microscopic counts in terms of monthly and seasonal averages. First horizontal line for each month is Company A, second is B and third is C.

Month	Plate Count	Direct Microscopic Count Bacteria per cc	Groups per cc
December	24,750	4,232,000	3,048,000
	1,290	4,188,000	3,632,000
	26,740	63,750,000	25,796,000
January	14,287	6,275,000	5,980,000
	850	3,035,000	2,730,000
	7,962	10,750,000	10,015,000
February	32,575	2,975,000	1,950,000
	34,612	5,750,000	5,230,000
	56,462	6,145,000	5,595,000
March	55,938	9,440,000	7,595,000
	13,400	1,445,000	1,280,000
	45,712	15,255,000	13,625,000
April	54,012	7,560,000	5,855,000
	26,887	1,645,000	1,340,000
	47,850	7,812,000	7,025,000
May	25,850	8,230,000	7,000,000
	14,740	6,295,000	5,355,000
	48,150	21,150,000	18,220,000
June	67,250	17,080,000	14,620,000
	25,340	20,430,000	18,400,000
	53,650	41,850,000	39,176,000
July	214,140	23,052,000	18,696,000
	34,400	39,616,000	29,250,000
	195,720	82,498,000	67,224,000
August	64,650	21,700,000	17,909,000
	36,300	24,100,000	20,580,000
	135,050	81,860,000	76,145,000
September	113,040	28,320,000	13,376,000
	22,560	11,104,000	6,736,000
	150,200	66,172,000	55,956,000
October	530,400	83,575,000	60,535,000
	46,875	7,300,000	6,130,000
	86,550	25,350,000	22,360,000
November	30,600	6,280,000	5,700,000
	11,100	7,420,000	4,640,000
	38,100	27,440,000	25,120,000

TABLE II—(Continued)

Comparison of plate and direct microscopic counts in terms of monthly and seasonal averages. First horizontal line for each month is Company A, second is B and third is C.

Month	Plate Count	Direct Microscopic Count	
		Bacteria per cc	Groups per cc
Winter	23,837	4,494,000	3,659,333
	12,230	4,357,666	3,864,000
	26,254	26,881,666	13,802,000
Spring	111,933	8,410,000	6,816,666
	18,342	3,128,333	2,568,333
	47,237	17,405,666	12,956,666
Summer	132,013	20,610,666	16,802,000
	32,013	28,048,666	22,743,333
	128,140	68,736,000	60,848,333
Fall	223,680	39,391,666	26,537,000
	26,845	8,608,000	5,835,333
	91,616	39,654,000	34,478,666

MOLDS FOUND IN INDIANAPOLIS MARKETS

By Paul Lentz

A number of molds are noted for the destruction they cause in fruits and vegetables, and have thus become a dreaded problem for dealers in these commodities. Although much work has been done on molds and hosts in general, comparatively little study has been given to date to the various kinds of fungi common to fruit markets of particular cities. An extensive paper on the subject has been written by Fischer (4), who studied the diseases of fruits found on the markets at Evanston, Illinois, during October, 1928 to March, 1929. He lists 29 genera of fungi found on various hosts, and includes notes on most of them. While Fischer's work was concerned with parasites and diseases of fruit alone, the present study is an analysis of the molds found upon both fruits and vegetables. Its purpose is to determine those molds which were most prevalent on the markets at the time this study was made, and furthermore, to attempt to associate the several molds with four main groups of hosts, viz: (1) those products growing beneath or near the soil; (2) the ordinary orchard fruits; (3) citrus fruits, and (4) the miscellaneous hosts which do not fit into any of the preceding groups. The present study was carried out in the Indianapolis markets.

The pathogenes were identified to genus only and in a limited way, some correlation was attempted between the pathogenes and the type of host upon which each seemed most prevalent. Taking, for example, a very familiar case: Penicillium occurs very frequently upon citrus fruits, to the exclusion, almost, of any other pathogenes upon this type of fruit. As an aid in this correlation, and for the sake of comparison and discussion, advantage was taken of data compiled over a period of several years in the Butler University Botanical laboratories, in addition to the results obtained from this study. During the years from 1935 to 1939, inclusive, these data were compiled from studies which were made for several weeks each year of molds found growing on various fruits and vegetables and their manufactured products. The results from the latter observations may not be taken as absolutely conclusive, since they were made by students in the department who had comparatively little experience in the identification of molds (genera numbers 22-35 in table II). However, they are reliable enough to use for comparison.

METHODS

A study was made of the market molds of Indianapolis during the three-month period from September 15 to Decmber 15, 1939. During this time fruits and vegetables which showed evidence of being hosts to molds were collected and the molds upon them were identified either macro- or microscopically. Each host vegetable was placed into a separate sterile dish, where it was permitted to remain until fruiting bodies were developed which would permit it to be identified. The macroscopic identification was made in the case of Penicillium, Rhizopus, and other easily recognizable genera, but was almost always supplemented by a microscopic examination. In the latter case, temporary slides were made of the fertile hyphae, and the fungus was thus traced to genus.

OBSERVATIONS

In the three-month period from September 15 to December 15, twenty-one genera of molds were identified from fruits and vegetables obtained from commission houses and markets (the first 21 listed in table II). Penicillium, identified from sixteen of the nineteen fruits and vegetables collected, was the most prevalent genus, followed closely by Rhizopus, which was identified from fifteen different hosts. Other molds which were identified from more than one host were: Alternaria, on six hosts; Aspergillus, four; Oospora, three; Fusarium, three; Monilia, two; Monosporium, two, and Isaria, two. Aspergillus, found on apple, cabbage, onion, and sweet potato, was the most prevalent of the molds found on the onion (table I). It was much more abundant on that host than either Penicillium or Rhizopus. Mucor, which is very closely related to Rhizopus, was found only on the carrot.

Approximately half of the molds identified were found on only one host (table II). There were several hosts from which more than one of these uncommon genera were obtained, viz.: (1) tomato: Sporotrichum, Stemphylium, Haplaria, and Monacrosporium; (2) banana: Spicaria, Trichosporium, and Pachybasium; (3) carrot: Mucor and Graphium. The potato was another host upon which several rare genera were found, Acremoniella being found only on the potato, and Isaria only on the potato and radish.

For the purpose of correlation of mold with host, the various fruits and vegetables were divided into the following groups:

(1) containing those vegetables and fruits which grow either beneath or near the soil, (cabbage, carrot, cauliflower, tomato, egg plant, mango, onion, potato, sweet potato, radish, and turnip) ; (2) including the fruits commonly found in the orchard (apple, peach, apricot, plum, and pear) ; (3) composed of the citrus fruits, (orange, lemon, and grapefruit) ; (4) made up of those hosts which were not placed into any of the preceding groups, (banana, cranberry, and grape).

Only fungi which were found on more than one host were used in the correlation. Because both Rhizopus and Penicillium were found on practically all of the hosts, neither was included in this discussion. The results of the correlation are contained in table III. It is seen in the table that Alternaria, Aspergillus, Oospora, Fusarium, Verticillium, and Isaria were found on a greater percentage of the hosts of group 1 than any other group, excepting, in several instances, group 4. Since the latter group is composed of totally unrelated hosts, its percentage results can be assigned no special significance, and the results of group 4 are used only when the particular mold is found on a number of hosts of group 4 equal to or greater than the number of hosts upon which the mold is found in any other group with which group 4 is being compared. Monilia, Macrosporium and Botrytis were fairly evenly distributed among the various groups ; while Monosporium was found on one host each in group 1 and group 4. In comparing group 1 with group 2, it is found that Alternaria, Aspergillus, Monilia, and Macrosporium were found on nearly the same percentage of hosts in the two groups ; while Oospora was found on exactly half the percentage of hosts in group 2 as in group 1.

Of the twenty-one genera of molds found between September 15 and December 15 on various market produce, Penicillium, Rhizopus, Aspergillus, and Alternaria were by far the most common. Penicillium was very common on practically all of the hosts, but was, of course, most prevalent on the citrus fruits. Rhizopus was common on the soil vegetables and orchard fruits, as was Aspergillus. Alternaria was isolated mostly from the soil vegetables such as cabbage and cauliflower, being especially prevalent on these two.

As a result of the attempt to correlate the various molds with the different types of hosts, it was found that while this may be done to a certain degree, it was not feasible to make this correlation

too definite. While certain of the molds such as Alternaria and Fusarium wre found predominately on the soil hosts, still the broad potentiality to endure a wide range in pH and moisture permitted most of the molds to grow upon various hosts. In general, it may be said that while the preceding two were limited mainly to the soil vegetables of group 1, Aspergillus and Monilia were more inclined to attack orchard fruits and Penicillium was predominantly the citrus fruit mold. In the miscellaneous group, Melanconium was found exclusively upon the grape, and Trichosporium was found only on the banana.

Several molds were identified in this study which had not previously been identified from uncooked fruits and vegetables in the Butler laboratories. These include Isaria, Haplaria, Synsporium, Monacrosporium, Trichosporium, Sporotrichum, Acremoniella, Melaconium, Graphium, Pachybasium, and Spicaria.

DISCUSSION

There are several factors which promote infection of market produce by molds. Among the most important of these are: (1) age, (2) treatment during production, (3) treatment during transportation, and (4) temperature and weather.

It is important that the fruits and vegetables which are to be sold on the market be firm and healthy. In order to assure this, very little time should elapse between picking and retailing; since a breakdown of the fruit tissue and subsequent susceptibility to fungus infection is a characteristic consequence of delay and prolonged storage. In relation to age, it may be said that the largest and oldest specimens of a particular fruit or vegetable are usually more susceptible to injury, decay, and infection than are smaller, more compact specimens (7).

A large percentage of the diseases of fruits and vegetables can be traced back ventually to the producer. Thus it is necessary that the fruit should be in good condition when it leaves the field. Many of the market diseases are but belated evidences of improper procedure and lack of care in production and harvesting. First, the seed should be disease-free and in good condition. Seed should be selected which will produce healthy plants. Then the plants should be kept in good condition by proper cultivation, and if necessary,

should be sprayed or otherwise treated to control fungus and insect parasites.

The treatment which fruits and vegetables receive in shipment is very important in determining what the condition of the produce will be when it reaches the market. Careless handling and improper packing may cause tremendous losses in transit (2). Bruised fruit and fruit with torn skins are especially susceptible to fungus invasion. Sound produce should, of course, never be transported or stored in proximity to diseased fruit.

Finally, weather and temperature are factors which may influence the soundness of market produce. Freezing may damage the crop in the field, in transportation, or on the market; while heat may cause damage in transit or on the market, or often may cause sunburn or scald in the field. Dampness may cause considerable loss in transportation.

It might be interesting to compare the relative amounts of spoiled produce which were evident in the various sources of pathogenes for this study. The Indianapolis Producers Market was a very profitable source of diseased fruit. This is an open air market in Indianapolis where growers may come to sell their produce (3). Much of the fruits and vegetables sold here are ungraded; thus there is a considerable spoilage. The commission houses, which supply the retailers, were also a good source of material for this work. As many as two or three bushels of spoiled bananas were sometimes thrown away Saturday noon by banana merchants, and these were accompanied by comparable amounts of other spoiled produce. The City Market was a very poor field for obtaining diseased specimens, and the retail grocery stores were only slightly better, although a continual dribble of such vegetables and fruits as spoiled carrots, radishes, and grapes was obtained from the latter. In general, it may be said that there is a gradual weeding out of the poorer quality fruits and vegetables from producer to retailer, so that the standard becomes higher as the produce undergoes a discriminative selection on its way from producer to consumer.

Several rather unique features appeared in this study. Bartholomew (1) says that with the possible exception of Penicillium, Alternaria causes more decay of California lemons than any other known fungus, and states that the loss due to Alternaria is equally high in other lemon growing regions. Yet Alternaria was not identified

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upon any of the citrus fruits in either of the studies incorporated into this paper (tables I and II).

A disease of grapes known as bitter rot has become widespread in the southern part of the United States (6). But thus far its appearance has been rather limited as far north as Indiana. Thus it is of some interest to note that the typical sooty spore pustules of Melanconium, the fungus causing bitter rot, were identified several times on grapes obtained from Indianapolis retailers.

SUMMARY

1. Twenty-one genera of molds were isolated from fruits and vegetables obtained from Indianapolis markets during the period from September 15 to December 15, 1939.

2. Penicillium, Rhizopus, Aspergillus, and Alternaria were the most common molds isolated, followed by Oospora, Fusarium, Monilia, Monosporium, and Isaria.

3. Plants which were host to four or more genera of mold include: Banana, cabbage, carrot, egg plant, onion, potato, and tomato.

4. In correlating genera of molds with types of hosts, it was found that Alternaria and Fusarium grow predominately upon hosts growing in or near the soil, Aspergillus and Monilia were more common upon ordinary orchard fruits; while Penicillium was the only genus found on the citrus fruits.

5. Melanconium which is somewhat out of its normal range in Indiana, was identified from grapes.

6. Mucor was isolated only once, from the carrot.

7. Molds identified in this study, which had not previously been identified from uncooked fruits and vegetables in the Butler laboratories include: Isaria, Haplaria, Synsporium, Monacrosporium, Trichosporium, Sporotrichum, Acremoniella, Melanconium, Graphium, Pachybasium, and Spicaria.

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TABLE I

Pathogenes listed by host. Those marked with * were found during the present study (September 15 to December 15, 1939). Others have been determined at other times by students in the class in microscopy.

Host	Pathogenes
1. Apple	Rhizopus*, Penicillium*, Aspergillus*, Alternaria, Mucor, Macrosporium, Rhizoctonia
2. Banana	Rhizopus*, Penicillium*, Aspergillus, Spicaria*, Mucor, Monilia, Monosporium*, Trichosporium*, Pachybasium*
3. Cabbage	Rhizopus*, Penicillium*, Alternaria*, Aspergillus*, Monilia*, Oospora*
4. Carrot	Penicillium*, Mucor*, Trichothecium, Rhizopus*, Oospora*, Graphium*
5. Cauliflower	Alternaria*, Oospora*
6. Cranberry	Alternaria, Penicillium*
7. Egg Plant	Rhizopus*, Macrosporium, Penicillium*, Alternaria*, Monosporium*
8. Grape	Penicillium*, Aspergillus, Botrytis, Alternaria*, Macrosporium, Melanconium*
9. Mango	Rhizopus*, Penicillium*, Fusarium*
10. Onion	Rhizopus*, Penicillium*, Aspergillus*, Synsporium*, Alternaria, Fusarium, Verticillium, Cladosporium, Botryosporium
11. Peach	Rhizopus*, Penicillium*, Monilia*
12. Pear	Aspergillus, Rhizopus*, Penicillium*
13. Plum	Rhizopus*, Penicillium*, Monilia*
14. Apricot	Oospora

TABLE I—(Continued)

	Host	Pathogenes
15.	Potato	Rhizopus*, Aspergillus, Fusarium*, Penicillium*, Verticillium, Stysanus, Mycogone, Rhizoctonia, Diplosporium, Mortierella, Acremoniella*, Dendrostibella, Acrostalagmus, Isaria*
16.	Sweet Potato	Rhizopus*, Penicillium*, Fusarium, Aspergillus*
17.	Radish	Fusarium*, Botrytis, Rhizopus*, Isaria*
18.	Tomato	Rhizopus*, Penicillium, Aspergillus, Sporotrichum*, Alternaria*, Oospora, Macrosporium, Haplaria*, Colletotrichum, Cladisporium, Stemphylium*, Monacrosporium*
19.	Turnip	Rhizopus*, Penicillium*, Monilia, Alternaria*
20.	Citrus Fruits	Penicillium*, Monilia, Botrytis, Macrosporium

TABLE II

Hosts listed by Pathogenes. The first 21 genera were found in the present study. The others were found in past years by students in the microscopy class.

	Pathogenes	Hosts
1.	Penicillium	apple, banana, cabbage, carrot, cranberry, egg plant, grape, mango, onion, peach, pear, plum, potato, sweet potato, turnip, citrus fruits, tomato
2.	Rhizopus	apple, banana, cabbage, carrot, egg plant, mango, onion, peach, pear, plum, potato, sweet potato, radish, tomato, turnip
3.	Alternaria	apple, cranberry, cabbage, cauliflower, egg plant, grape, tomato, turnip, onion
4.	Aspergillus	apple, banana, cabbage, grape, onion, pear, potato, sweet potato, tomato
5.	Oospora	apricot, cabbage, carrot, cauliflower, tomato
6.	Fusarium	mango, onion, potato, sweet potato, radish
7.	Monilia	banana, cabbage, peach, plum, turnip, citrus fruits
8.	Monosporium	banana, egg plant
9.	Isaria	potato, radish
10.	Mucor	carrot, apple
11.	Haplaria	tomato
12.	Synsporium	onion
13.	Monacrosporium	tomato
14.	Trichosporium	banana
15.	Sporotrichum	tomato
16.	Acremoniella	potato
17.	Melanconium	grape
18.	Graphium	carrot

TABLE II—(Continued)

	Pathogenes	Hosts
19.	Pachybasium	banana
20.	Stemphylium	tomato
21.	Spicaria	banana
22.	Macrosporium	apple, egg plant, citrus fruits
23.	Rhizoctonia	apple, potato
24.	Trichothecium	carrot
25.	Verticillium	onion, potato
26.	Cladosporium	onion, tomato
27.	Botryosporium	onion
28.	Stysanus	potato
29.	Mycogone	potato
30.	Diplosporium	potato
31.	Mortierella	potato
32.	Dendrostilbella	potato
33.	Acrostalagmus	potato
34.	Colletotrichium	tomato
35.	Botrytis	citrus fruits

TABLE III

Correlation of pathogenes with host types. Column one of each group indicates number of hosts from that group upon which the mold was found. Column two of each group represents the percentage of total hosts of that group upon which the mold was found.

	Pathogenes	Group 1		Group 2		Group 3		Group 4	
1.	Alternaria	6	54%	2	40%	0	0%	2	66%
2.	Aspergillus	5	45%	2	40%	0	0%	2	66%
3.	Oospora	4	36%	1	20%	0	0%	0	0%
4.	Fusarium	5	45%	0	0%	0	0%	0	0%
5.	Monilia	2	18%	1	20%	1	33%	1	33%
6.	Macrosporium	2	18%	1	20%	1	33%	0	0%
7.	Botrytis	1	9%	0	0%	1	33%	1	33%
8.	Verticillium	2	18%	0	0%	0	0%	0	0%
9.	Isaria	2	18%	0	0%	0	0%	0	0%
10.	Monosporium	1	9%	0	0%	0	0%	1	33%

Group 1—Soil vegetables.
Group 2—Orchard fruits.
Group 3—Citrus fruits.
Group 4—Miscellaneous hosts.

COMPARISON OF POLLEN SPECTRA FROM BOGS OF EARLY AND LATE WISCONSIN GLACIATION IN INDIANA

By Dayton A. Swickard

As is well known, Indiana was within the path of the Illinoian and both the Early and Late Wisconsin ice sheets. The Illinoian glacier, coming earlier than the Wisconsin glacier, extended the entire length of the state along both the east and west borders, leaving a large south-central portion unglaciated. The unglaciated area has its northernmost boundary in Monroe county with its southernmost limit on the west, Posey county, and on the east, Clark county. The Illinoian drift was covered by the Early Wisconsin glacier, whose southern border made an irregular line from Vermillion county on the west, southeast to Franklin county on the east, with its southernmost extension reaching the tip of Jennings county in the south-central portion of the state.

The Late Wisconsin drift did not extend its outer border so far south. Its southern limit begins in Benton county on the west and makes an irregular line southeastward, as in the Early Wisconsin drift, to Randolph county on the east. These last two glacial periods were most active in that they left vast pits and kettle holes which probably soon became lakes, and by later filling in turned into bogs. Sufficient time has elapsed since the retreat of the Early Wisconsin period to obliterate every lake south of the Late Wisconsin border and only deep deposits of peat, amounting to as much as 43 feet, bear record of their past existence.

Two bogs were included in the present study, Yountsville bog in Montgomery county, within the border of the Early Wisconsin territory, and Mill Creek bog in Laporte county, located within the territory of the Late Wisconsin glaciation. Yountsville bog is 8 miles west and one mile south of Crawfordsville, near the Prairieville road, on the farm of William Runyon. The Mill Creek bog is one mile north of Mill Creek. This is a border county on the Michigan-Indiana line. It is located well in the Northern Moraine and Lake Region and is a part of a great outwash apron which has an altitude of 775-800 feet at the margin of the Moraine. This apron constitutes an extensive gravel plain made by drainages of ice during the deposition of the Kalamazoo Moraine (Malott, 6). The drainage of this

county is chiefly through the broad valleys of Crooked and Mill Creeks.

THE STATUS OF THE BOGS

Yountsville bog is an extinct bog, the peat having solidified enough to permit cultivation. It covers approximately 20-25 acres with a central area of approximately 1200 feet by 800 feet which is still quite wet during the rainy seasons. The portion surrounding this central area has all been disturbed by cultivation, by washing in of the surrounding soils, and by a gravel lane which has been built over its surface. The water table is high, holes dug on the surface during boring observations showed the water within one foot of the top.

Two borings were made in this central area of the bog, designated as boring "A" and "B." Boring "A," the deeper of the two borings, recorded peat accumulation to a depth of 24 feet. Boring "B," made some 200 feet from "A," was only 15 feet deep. The peat from the deeper boring, "A," was used for analysis. The Yountsville bog is of the typical kettlehole type. It is circular in shape with fringing gravel hills around the periphery.

Mill Creek bog is in a more youthful stage; the soil is very soft and wet during the entire year. This bog resembles more nearly an old river bed which has turned into a lake. The length is probably 9 or 10 miles. Following approximately the course of the old river bed is a wet ditch that continues south, emptying into Mill Creek. The drilling was made in what was thought to be the deepest area. Only one boring was made and the depth reached was 59 feet. The drilling took place in the southern half of the bog about one mile north of Mill Creek. A short distance north of the drilled area is an island about which the old river probably made its course. The channel on the eastern side of the island is more shallow than the channel on the western side, because in this channel there is a small wet area which has not as yet filled in and is covered by water. The eastern border is made of forested hills which rise sharply from the edge of the bog.

PRESENT DAY VEGETATION

The present day vegetation of Mill Creek bog is typical of developing bogs. The bog surface itself is a sedge meadow, while the

gravel ridges surrounding are dense with *Quercus velutina,* and *Quercus alba. Acer rubrum* also was found, not only on the gravel ridges, but in the boggy lowlands, as well. In a wooded area south of the boring an abundance of *Larix laricina* was found, together with scattered individuals of *Pinus strobus.* Plants typical of boggy soil were: *Potentilla fruticosa, Solidago ohioensis, S. riddellii, Prosperapinaca palustris creba, Boehmeria drummondiana, Lobelia kalmii, Osmunda cinnamomea, Cypripedium reginae. Rhus vernix, Vaccinium corymbosum atrococcum, Pedicularis lanceolata, Osmunda regalis spectabilis, Gentiana procera, Solidago uniligulata,* and *Parnassia americana.*

Plants typical of swamps and bogs throughout the United States, found here, were: *Cicuta bulbifera, Cicuta maculata, Lythrum alatum, Penthorum sedioides, Rosa palustris, Mariscus mariscoides, Oxypolis rigidior, Sagittaria latifolia, Nuphar advenum, Symplocarpus foetidus, Caltha palustris, Phragmites communis, Typha latifolia, Scirpus validus,* and *Decoden verticillatus.* Plants more often found growing in the coastal plain region were also found: *Mimulus rigens, Bartonia virginica, Triglochin palustris,* and *T. maritima.* Northern plants having their southern limits in the northern Indiana lake region and found in the bog were: *Campanula rotundifolia, Bromus kalmii, Betula lutea, B. pumila, Rhamnus alnifolia, Maianthemum canadense, Selaginella apoda* and *Galium labradoricum.*

No special study was made of the plants in the Yountsville area because natural vegetation is almost entirely eliminated by agriculture. It must be noted, however, that this is only six miles from the Pine Hills area, a famous spot in Indiana because of relic colonies of such northern plants as: *Pinus strobus, Taxus canadensis, Tsuga canadensis, Gaultheria procumbens,* and *Cornus rugosa.* This area was studied in detail by Friesner and Potzger (2).

METHODS

The samples were taken similarly to those previously collected for other bog studies in this department (1, 5, 9, 13). Samples were collected at one foot intervals, beginning with the surface layer, except at the Yountsville bog where a one-half foot level was taken between the surface and the one-foot level. The technique used in the laboratory was that suggested by Geisler (3), probably described best as the alcohol method. A scalpelful of peat was placed in a small beaker; to this sample was added about 10-15 cc of 95% alco-

hol. Then from one to five drops of 1% aqueous solution of gentian violet was added and the material was stirred for several minutes. It was found in staining the material from the Mill Creek bog, that the lower depths required more stain. As Smith (17) stated, the alkinity of the lower levels required much more stain to make a well stained slide.

It was found in both bogs that if the slides were allowed to stand for a few days the pollen became more fully stained. This was particularly true of Yountsville bog, where a week or more was required before the grains began to show any color. Pollen determination was made with the aid of a binocular microscope equipped with 43X objective and 15X oculars. To familiarize the observer with the pollen grains encountered, the illustrated references of Sears (18) and Wodehouse (22) were used. There were also available permanent slides of known pollen grains which could be compared with the grains from the bogs.

The pollen frequency was based upon a count of 200 grains per foot-level. Foot-levels 25, 11, 10, 9, and 7 are absent from the spectrum of the Mill Creek bog, because the peat was so dilute at these levels that it was impossible to make collections. This is indicated by a "w" in the graph. At the one-half foot and surface levels in the bog, only 100 grains were counted because of the lower number encountered.

OBSERVATIONS

Mill Creek Bog

The pollen spectrum from the Mill Creek bog was found to be typical of bogs observed by other workers in Indiana. The lower levels show dominance by Abies and Picea. In the 59-foot level, as well as the 55-foot level Abies has a percentage of 59.5. Picea was represented by 38.5%. Two other genera were represented in the lower levels, viz. Quercus and Pinus, both with low percentages. Abies showed its first signs of losing importance at the 51-foot level, where its percentage dropped to 18.5, while Picea dropped to 11.5. Quercus had been present from the lowest levels and with this decrease in Abies and Picea in the 51-foot level it gained in relative importance. In the next level, however, Abies again increased in importance, having a percentage of 28.5 to 25 for Quercus. Picea

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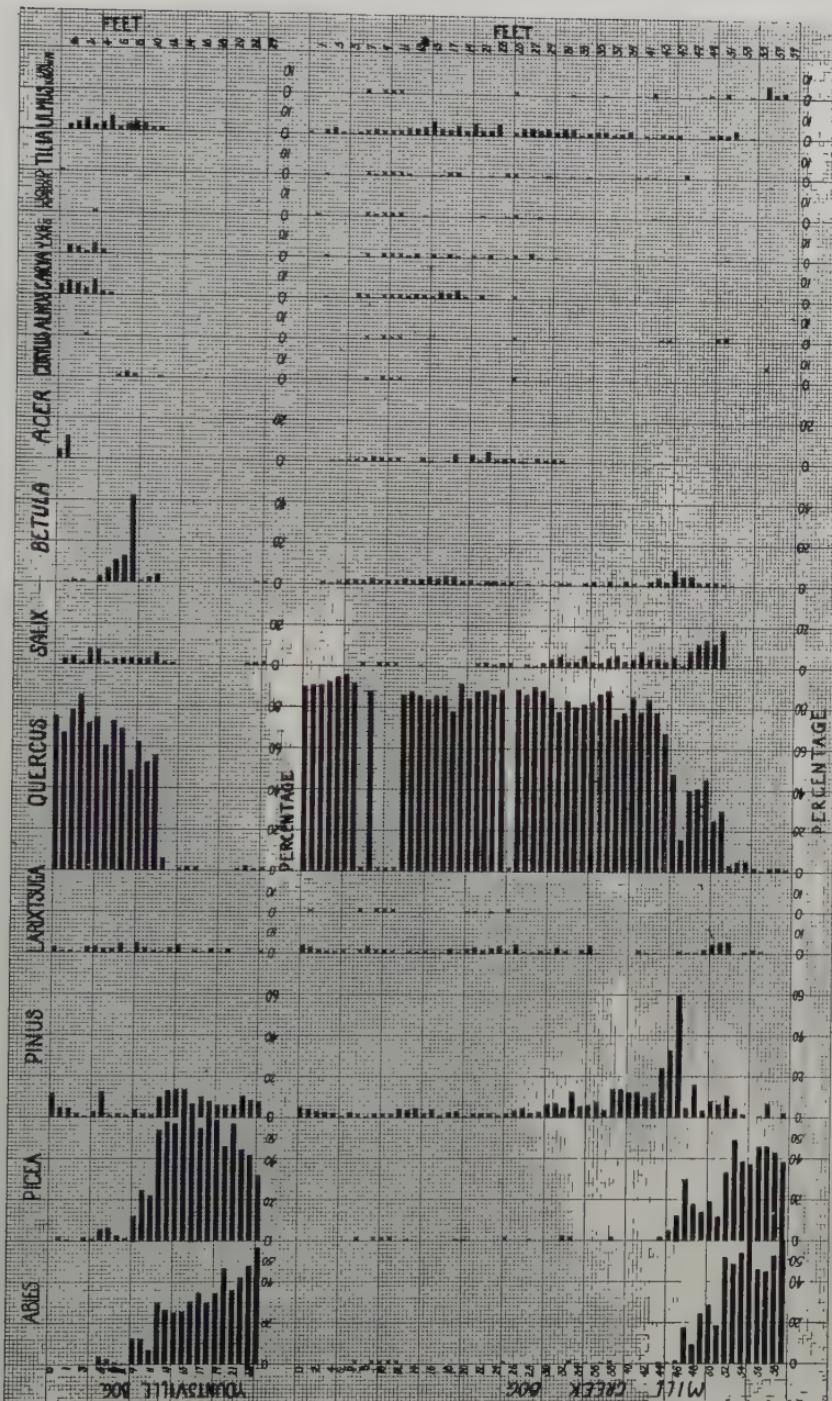
also gained with an increase to 19%. At the 49-foot level Quercus again increased in importance with a percentage of 45. Abies dropped to 2%, and never showed any importance after this foot-level, disappearing entirely at the 33-foot level. Quercus was now the important genus of the spectrum and continued to be up to the 46-foot level. Secondary in importance was Picea which had now gained over Abies and continued to lead until it disappeared completely at the 13-foot level. At the 46-foot level there was a decisive change in the spectrum. Pinus, which had occupied a position of minor importance, now showed a sharp increase from 4.5% in the 47-foot level, to a dominating percentage of 60. This was the only level in which Pinus dominated; but, in the next two foot-levels (i. e. 45 and 44), the percentage was high enough to form a Quercus-Pinus association.

After the dominance of Pinus in the 46-foot level, Quercus became the most important genus of the spectrum. It held a dominance from the 43-foot level on to the surface with percentages which never dropped below 75.5. No Larix grains were found in the lower 3 foot-levels. It appeared at the 56-foot level with a respresentation of 0.5%. From here to the surface it appeared and disappeared in the various levels. The highest percentage reached was 6.

Tsuga had the least representation of all genera; it was present only in 4 levels in very low percentages. All other genera were represented by unimportant percentages; Salix appeared in the 51-foot level with a percentage of 18.5, the highest representation for it in the spectrum. It finally disappeared in the 21-foot level. Betula came in at the 52-foot level and persisted in low percentages to the 3-foot level.

Other broadleaved genera, Alnus, Acer and Ulmus, were found in small percentages. Acer came in at the 31-foot level and was present until the 2-foot level. The percentage representation was never very high, the highest being 5% in the 22-foot level. Ulmus was persistent in its presence, but never reached significant representation. It made its appearance in the 54-foot level, and its highest percentage was 6.5 in the 15-foot level. Carya, Juglans, Liquidambar and Tilia appeared in small percentages and at varying levels between the 46-foot level and the surface.

Yountsville Bog

In the Yountsville bog Abies and Picea were dominant in the lower levels as in the Mill Creek bog. The dominance of the two continues for a much longer period of time than in any bog yet analyzed in the Early Wisconsin glaciation territory. Abies showed dominance only in the 24-foot level with a percentage of 56.5. From this level to the 19-foot level Picea was a co-dominant with Abies, but at the 19-foot level Picea became the dominant species and remained so to the 11-foot level. Abies, however, continued its presence in the spectrum and did not disappear until the 5-foot level. This probably is a new record for the presence of Abies in bogs thus far studied in Indiana. Picea was present in almost the entire spectrum of the bog; it was found up to the 0.5-foot level, after having been absent in the 2-foot level. The highest percentage reached was 60, in both the 18- and 16-foot levels.

Pinus was the only genus which was present through the entire spectrum. Howell (5) and Richards (13) reported this to be true also in the Kokomo and Otterbein bogs. Pinus never reached a dominant stage, its highest percentage being 13.5 in the 14- and 15-foot levels. Larix was present in the 24-foot level but disappeared and did not reappear until the 20-foot level. From this level to the surface it persisted in low percentages.

The broadleaved genera Quercus, Salix, and Betula were all present in low percentages at the bottom foot-level. Quercus appeared in the spectrum to the 20-foot level, here it disappeared until the 16-foot level. In the 11-foot level Quercus gained control and remained dominant to the surface level. The highest percentage reached by Quercus was 85, in the 2-foot level. Salix was present in the lowest three levels but, like Quercus, it disappeared not appearing again until the 13-foot level after which it remained in small percentages until it disappeared entirely at the 0.5-foot level.

Like Quercus and Salix, Betula disappeared after the 23-foot level, but reappeared at the 11-foot level. At the 8-foot level it became unusually prominent, reaching a representation of 42.5%, almost equalling Quercus at this stage. In the next level it dropped to 13% and finally disappeared at the 0.5-foot level. Acer was present only in the upper two foot-levels, reaching 11% at the 0.5-foot level but declining in the surface layer. Carya did not appear until the 5-foot level from which it remained in small representation to the

surface. Corylus and Alnus were both present to the 0.5-foot level where it disappeared never reaching more than 7%. Juglans was found in the 4-foot level lasting to the 0.5-foot level, but never having a high percentage. Tilia and Liquidambar were found only once in the spectrum. Liquidambar is listed with hesitation because of its present day range, but measurements and characteristics of the pollen grains agreed perfectly with published descriptions and to date no other pollen of herbaceous or woody species has been found which might be mistaken for Liquidambar.

DISCUSSION

The Early Wisconsin Glacial Drift

A lake is one of the most short lived of all topographic features. Practically all natural depositional agents tend to destroy lake basins by silt, wind-blown sands, or accumulation of plant and animal remains. It has been estimated that about one-fourth of Indiana is still or has been occupied by lakes in recent geological time (Malott, 8). The lakes formed during the Illinoian glacial retreat are all extinct or they have been obliterated by the Early Wisconsin glacier. All of the natural lakes or bogs in Indiana are products of the Early or Late Wisconsin glaciation. Great changes have taken place in the condition of the lakes in Indiana since the state was first settled. According to Malott (8), the last fifty years have witnessed the reduction of actual lake surface by at least one-half, probably due to natural causes coupled with artificial drainage. The lakes of Early Wisconsin drift are all closed chapters as lakes and have changed into mature bogs. The soil of the bogs of the Early Wisconsin glaciation has solidified to such an extent that farm cultivation is taking place upon its surfaces.

The Wisconsin glaciation in Indiana covered approximately 22,-900 sq. miles and the margin made by it was distinctly lobate, a characteristic which became accentuated as the ice retreated to the northward. Leverett and Taylor (7) in their discussion of the lobation of the Indiana region states that they were local deployments down major valleys. Malott (8) states that the oldest section of the Late Wisconsin drift in Indiana is a section from Lafayette to Terre Haute; this is marked by large streams such as the Wabash river, and also by considerable dissection of the glacial plain itself.

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In this section is located the Yountsville bog, included in this study. The bog analyzed by Richards (17) in Warren county is also within this region. In other sections of the Early Wisconsin boundary, bogs have been analyzed by Howell (6) in Howard county, Otto (12) in Marion county, Prettyman (16), Hamilton county, and Barnett (1) in Madison county. All these bogs were quite similar as to pollen records in the lower levels; all showed a forest dominated by Abies and Picea.

The behavior of Picea and Abies in the Yountsville bog was quite different from that of other bogs in the Early Wisconsin glaciation. In no other so far studied, did Abies and Picea persist so long as they did here. Picea was present to the 1-foot level and Abies persisted to the 5-foot level. Abies was dominant in the bottom level, but lost its dominance in the next level. This dominance was then taken over by Picea, and lasted to the 11-foot level where it gave way to Quercus. In the Otterbein bog, Bacon's Swamp and Kokomo bog, Picea had a similar representation. The dominating percentage of representation of Picea was about the same in all these bogs but the duration of dominance (8-foot levels) was longest at the Yountsville bog. This evidence of a well expressed boreal forest in the lower levels of the Yountsville bog agrees with the results of others and, according to Sears (19), indicates a cool-humid climate. Its persistence for so many foot-levels is hard to explain. A possible explanation is the one given by Howell (6), that the cool seepage water from the northeast and central part of the state drained to the southwest through the Wabash river basin making ideal conditions, i. e. cool soil for the reproduction of Picea and Abies, for a much longer period of time than in other areas from which the ice had retreated. In other words, persistence is evidently due to favorable local conditions, making it possible for these species to persist as relics in a macro-climate belt favoring broadleaved species but with a local micro-climate favoring the boreal species. This same region, as reported by Friesner and Potzger (2), has even today a well-developed colony of northern plants, e. g. *Pinus strobus, Taxus canadensis, Tsuga canadensis, Cornus rugosa, Diervilla lonicera,* and *Gaultheria procumbens* at Pine Hills which is only six miles to the south of the big site. The persistence of Pinus to the top foot-levels of the bog indicates that it had up to recent times a wider distribution as a relic in Montgomery county.

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Larix was present in Yountsville bog in small percentages at intervals throughout the spectrum. Larix pollen is very fragile, and even the slightest pressure may break the exine, making the pollen unrecognizable. This is probably the reason why it shows such low percentages even though Larix may have had a greater percentage representation in the forest canopy. Yountsville bog had no record of Tsuga. In the other bogs it was found at different foot-levels throughout the spectrum with low percentages. Tsuga pollen is noted for its rapid disintegration when the pollen becomes wet, and so its absence does not necessarily mean non-representation in the forest complex. It is almost certain that Tsuga should have been in the forest complex of that region for it is present even today in the relic colony at Pine Hills which is only a few miles from the bog.

The percentage of Quercus in the Yountsville bog was higher than in any of the other bogs compared in the Early Wisconsin region. In the Yountsville bog it was slow in gaining dominance, much slower than in the other bogs, due to the long persistence of Picea and Abies, but once it gained control it dominated as in all other bogs. It is difficult to say whether the long Abies-Picea dominance is due to delayed change in macroclimate or to some unusually favorable local or microclimate control. Again it may mean that in a shallow lake, represented by the bog, filling was completed before the latter part of the succession could be included in the depositional record. The Otterbein, Kokomo, Cranberry, Fox Prairie, and Bacon's Swamp bogs all have Quercus persistent in the upper levels, but like Yountsville, they had a co-dominant species associated with it in the topmost levels. The usual co-dominant species of the other bogs were either Carya or Acer. In the Yountsville bog Acer became a co-dominant in the 0.5-foot level. Quercus, however, was still the dominant genus and had controlled since the 11-foot level. The spectrum suggests a very slow change from a cool-moist climate, as indicated by the persistent Picea and Abies dominance, to a warm-dry climate as indicated by the Quercus climax. The appearance of Acer in the last two foot-levels probably indicates a change from a warm-dry climate to a warm-moist climate. The percentage of Acer may mean more than it represents in the spectrum, since Acer pollen is not produced in such abundance as Quercus and so a small percentage of this genus may be comparable to a larger percentage of Quercus.

Bacon's swamp is the only bog studied in the Early Wisconsin territory of Indiana which had an ultimate Acer-Quercus climax. More evidence for the change to a warmer climate was the sudden increase in Betula, in the 8-foot level (42.5%), which persisted for 2 foot-levels. It is thus possible to state that the forest succession of Yountsville bog was: Abies, to Abies-Picea, to Picea, to Quercus, to Quercus-Acer. The climatic change being from a cool-moist to a warm-dry, to a warm-moist.

The Late Wisconsin Glacial Period

The Late Wisconsin glacial advance was not so far southward; neither was it so extensive in area as the early advance. The bogs and lakes of this moraine region are much younger than those of the early drift. The bogs are still in their formative state, many of which have almost filled in but are yet very wet in rainy seasons. The time elapsed since the Wisconsin glacier made its last appearance has had some dispute. Cleland (24), basing his estimates on the recession of the Niagara gorge, and of St. Anthony's Falls, estimates that the permanent retreat of the Wisconsin ice sheet was between 12,000 and 20,000 years. This would be added to the time during which the ice retreated from the southern limit to the Niagara gorge. According to Miller's (10) estimate the retreat required about 12,000 years from its southern boundary (about Logansport for Indiana) to the Niagara gorge. Antevs (23), estimates the beginning of the retreat as between 30,000 and 40,000 years. The question had frequently been raised whether or not it is possible to calculate back through the centuries using the bog sediments as criteria. Potzger (14) states, that Dachnowski estimates 200 years for the accumulation of one foot of peat; Soper and Osbon estimate 600 to 1200 years per foot of peat, and Sears, about 300 years to the foot. Potzger (14), also states that the average depths of bogs in Indiana is about 35 feet and if based on Sear's estimate we would have 10,500; if based on Soper and Osbon it would be 21,000 to 42,000 years, the latter computation correlating more with Cleland and the Niagara gorge recession. It must be kept in mind, however, that there is a possibility of large discrepancy in such estimation.

The withdrawal of the ice north and eastward in Indiana was attended by the position of three distinct sets of roughly concentric terminal moraines. In northwestern Indiana the moraines were built by the Lake Michigan lobe. In the northeastern part of the state the

moraine system is in harmony with the Main Erie lobe, while in north central Indiana the moraines conform to the position of the enclosed Saginaw lobe. These orderly arrangements of the systems are in keeping with the lobation of the ice. Malott (9) considers these formations due to halts or temporary readvances of the ice margin. Since these advances and retreats of the glacial sheet many miniature lakes, left by this activity, have been filled by inwash or accumulations of plant remains. Many larger basins have become smaller, but are still lakes. The areas of these small shallow basins are now marked by level depositions of black earth. In such a region is located the Mill Creek bog with its accumulation of peat to a depth of 59 feet, and is one of the deepest bogs of Indiana yet analyzed.

Abies was dominant in the lower 2 or 3 foot-levels of Mill Creek bog, forming a Picea-Abies climax later. Moss (11), found in Altona bog a very short dominance by Abies with Quercus and Pinus appearing early in the spectrum. In comparison it was found that in all areas Picea-Abies did not endure very long, about 2 or 3 feet, before Pinus assumed control. This means without a doubt that the cool-moist climate was beginning to shift to a cool-dry condition. As the glacier began to melt, the drainage water was carried by the Wabash and Kankakee valleys, and as this water was carried away the conditions became drier. This evidently coincided with the fast reproduction of Pinus. However, the climate still must have been cool since our northern Pine today retains dominance in a cool-dry habitat.

Weaver and Clements (21) say that Larix is a persistent sub-dominant species in the boreal forests of today. The pollen spectra show that Larix held a similar position in the early Post Pleistocene forests. Potzger and Wilson (13) state that Larix is found today as a dominant in relic colonies deep in the deciduous forests, again showing its ability to adjust itself in order to persist over a wide area through Picea and Abies forests to the southern deciduous forests.

In the Mill Creek bog Quercus never shared dominance with another genus. In the Lakeville, Round Lake, Loon Lake, Altona and Lake Cicott bogs, Quercus was associated in the upper levels with Carya. In Winona lake the representation was Acer and Quercus. Tippecanoe lake was very similar to Mill Creek bog in having only Quercus as a major species represented in the upper levels. It is justifiable to assume that the climatic changes were more or less

uniform in all instances, probably from cool-moist to cool-dry, to a warm-dry to a more warm-moist climate. Potzger and Wilson (13) assume that this was the case in the Winona and Tippecanoe lake region. The fluctuations between Pinus and Quercus and the association of the two were induced by local control. Characteristics such as these are found in forests of today. Potzger and Friesner (15) have shown that in central Indiana north-facing slopes not over a few hundred feet from south-facing slopes, have a Fagus-Acer climax while the opposite slope was covered with Quercus or Quercus-Carya. Such phenomena must be considered when translating the post glacial successions.

Betula and Salix were represented in Mill Creek bog in small percentages which correlates with conditions in Winona and Tippecanoe lakes, while in bogs observed by Moss (11) and Hamp (4) they were slightly higher. Potzger and Wilson suggest that the low count of Betula and Salix may be due to the fact that these trees shed their pollen early and the frozen condition of the lakes would interfere with the deposition of these pollen to the sediment for preservation.

Betula lutea and *B. pumila* are found growing in the bog site today. These are northern species growing in their southern limits in Indiana. Betula pollen were first found in the 52-foot level; it may be assumed that this was the time when these species came to what was then their northern limits and which is today their southern limits.

Comparison of Yountsville and Mill Creek Bog

The most outstanding difference between the Yountsville and Mill Creek bogs is, perhaps, the expression of the Picea and Abies climax. At Yountsville the control by Picea and Abies continued to a time when about two-thirds of the sediment had accumulated while at the Mill Creek bog it waned when about one-third of the sediment had accumulated. This bog correlates in the Picea-Abies climax more with a bog that should be located in southern Michigan, or at that latitude. Potzger and Wilson (13) state that bogs studied in Michigan do indicate that Picea and Abies extend in the spectrum to very high levels and percentages. The situation that exists at Yountsville bog may be opposite to the situation found at Altona (Moss, 11).

Yountsville bog is quite shallow and it is possible that it became filled before the complete pollen spectrum to the present could be recorded. Then, too, it is very likely that during the occupancy by civilized man, repeated fires might have eliminated the top-most layers. Such argumentation offers explanation for other features in the spectrum, especially the behavior of Acer, coming in so suddenly in the 0.5-foot level. The Acer-Quercus climax may have been more persistent, but may not be recorded in the sediments now present.

The Mill Creek bog, in the lower levels showed typical Abies-Picea climax for a short period and then its dominance was lost never to be regained. Pinus played quite a different role in the Mill Creek bog than in the Yountsville bog. Pinus in the Mill Creek bog made a sudden increase for 2.5 foot-levels, enough to establish a dominance or at least to form a strong co-dominance with Quercus. In other bogs of this Late Wisconsin glaciation region shown in table I, Pinus made a similar increase in the correlating foot-levels.

TABLE I

Foot-levels with Pinus an important genus in Late Wisconsin bogs.

Name of bog or lake	Number of foot-levels with Pinus an important genus
Loon Lake Bog	3 feet
Altona Bog	2 feet
Winona Lake	2 feet
Tippecanoe Lake	2 feet
Lakeville Bog	1 foot
Round Lake Bog	0
Mill Creek Bog	2.5 feet
Lake Cicott Bog	5-7 feet
*Mineral Springs Bog	2 feet
*Center Lake Bog	2-4 feet

*Investigated by Houdek (5).

In comparison with bogs of the early Wisconsin glaciation it was found that none in areas of Early Wisconsin glaciation showed this sudden increase in Pinus. In these bogs Pinus persisted only in un-important percentages to top levels. It is believed that in the Early Wisconsin regions the climate change was a cool-moist turning directly into a warm-dry. In the Late Wisconsin region, farther north, there was an additional change. The Pinus dominance showed this, meaning that there was a time in which a cool-dry climate ex-

isted. The number of foot-levels for this intervening climate varies with the bogs, probably depending upon the rate at which deposition occurred or as influenced by local edaphic factors. There is another interesting difference in vegetational behavior in areas of Early and Late Wisconsin glaciation. Picea was generally present to a much higher foot-level in the Late Wisconsin bogs than in the Early Wisconsin bogs. Table II shows the difference between the two.

TABLE II

Presence of Picea in Various Spectra

Late Wisconsin Bogs		
Name of Bog	Depth of Bog in Feet	Foot-level at which Picea disappeared
Loon Lake Bog	41	2
Altona Bog	23	2
Winona Lake	33	0
Tippecanoe Lake	59	3
Lakeville Bog	30	0
Round Lake Bog	32	0
Mill Creek Bog	59	12
Lake Cicott Bog	31	13
*Matthews Bog	29	0
Early Wisconsin Bogs		
Kokomo	32	6
Bacon's Swamp	32	10
Fox Prairie	28	23
Otterbein	44	4
Cranberry	32	17
Yountsville	24	0.5

*On outer border of Late Wisconsin glaciation.

In the Matthews bog, Picea was present to the top foot-level. This bog is located close to the border of Late Wisconsin and Early Wisconsin glaciations. The only bog in the Early Wisconsin region that has Picea at the top level was Yountsville.

These results of Yountsville and Mill Creek bogs permit the conclusion that there was a difference in forest succession between areas in Early and Late Wisconsin glaciations in Indiana. However, one must not jump at conclusions, stating that these differences are complete, for there is much work yet to be done before generalizations seem entirely justifiable.

SUMMARY

1. The paper presents pollen spectra from Mill Creek and Yountsville bogs.

2. Yountsville bog is located in an Early Wisconsin glaciation region, and Mill Creek bog in a Late Wisconsin region.

3. The Yountsville bog is of the kettle hole type, while the Mill Creek bog is of the valley type.

4. Both bogs showed a forest controlled by an Abies-Picea climax while the lower levels were being deposited.

5. Abies-Picea persisted to higher levels in the Yountsville bog than in the Mill Creek bog.

6. Mill Creek bog showed dominance by Pinus at the 46-foot level.

7. Pinus was present in low percentages throughout the spectrum at Yountsville.

8. In all but Round Lake bog, Pinus assumed dominance during one or more foot-levels in all bogs located within Late Wisconsin territory but never in bogs located in Early Wisconsin territory.

9. Picea was consistently present to a much higher foot-level in bogs of Late Wisconsin territory than in bogs located in areas of Early Wisconsin glaciation.

10. Quercus became dominant in Mill Creek bog at the 44-foot level and remained dominant to the top levels.

11. At Yountsville bog Quercus dominated from the 11-foot level to the surface but gave way to a Quercus-Acer association at the 0.5-foot and top levels.

12. Succession at Yountsville was: Abies to Picea-Abies, to Quercus, to Quercus-Acer; succession at Mill Creek bog was: Abies to Picea-Abies, to Pinus, to Pinus-Quercus, to Quercus.

13. Climatic changes at Yountsville may be expressed as cool-moist, to warm-dry to warm-moist; changes at Mill Creek were from cool-moist, to cool-dry to warm-dry.

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A PRELIMINARY STUDY OF GROWTH IN THE BEECH, FAGUS GRANDIFOLIA, BY THE DENDROGRAPHIC METHOD

By Ray C. Friesner

Dr. D. T. MacDougal has given a very comprehensive review of his own and the studies of others on the growth of trees in his recent publication, "Tree Growth" (Chronica Botanica Company, 1938). A large number of species: evergreen, deciduous, native and introduced have been studied by the various workers.

Of the narrowleaf evergreens, Monterey Pine, *Pinus radiata* (7), has received the most exhaustive study. In general, it may be said that the time of initiation of growth depends largely upon the temperature, and time of cessation varies from year to year, depending largely upon time of exhaustion of water supply. In all cases the growth curve rises rapidly to a maximum and falls off, often rapidly, but continues some growth for a longer period of time than was occupied in the rise to the maximum. In *Sequoia sempervirens* (7) the growth curve generally begins later in the year and more often continues throughout the year. The falling off from the maximum is, therefore, spread out over a greater period of time. Diametral increase in trunks of evergreen conifers is not dependent for initiation upon the beginning of bud activity.

In broadleaf deciduous trees the initiation of cambial activity usually follows some time after the initiation of bud activity. In most cases diametral increase, at least near the base of the tree, begins about the time when leaves are nearly or fully expanded. In *Acer saccharum* (MacDougal, 7) diametral increase first registered on the dendrograph at the time when the leaves had attained full expansion. Similar results are reported for *Acer macrophyllum* and in the brief study reported for *Fagus grandifolia*. Lodewick (4) found that diametral growth in *Ulmus americana* began in early May but did not reach any considerable amount until near the end of May when leaves had reached their full size. In *Quercus velutina* cambial activity began about the time of swelling of buds and spring wood was completely formed by the time the leaves had reached full expansion, i. e., by mid-June. Similar conditions are reported for *Q. borealis maxima*. Studies on *Fraxinus americana* (Lodewick, 5) revealed that growth began two days after the swelling of leaf

buds and spring wood was completed by the time leaves had reached full expansion.

The most notable exception to the general statement made above is the results of Chalk (1) on *Fraxinus excelsior* and *F. oxycarpa* and those of MacDougal (7) on *F. velutina*. Diametral increase in all parts of the trunk took place a week before the flower buds opened and three weeks before the swelling of the leaf buds began. Five to nine per cent of the xylem had been formed by the time the leaf buds began to open and 30% had formed by the time the leaves were half expanded. Hanson and Brenke (3) found that xylem formation had reached 360 microns by the time the leaves were fully expanded in *Fraxinus campestris* and *Acer saccharinum*. Korstain (Mac-Dougal, 7) found that diametral increase in *Acer negundo* began when leaves had attained about half of their full expansion. In general, it may be said that cambial activity begins earlier in relation to bud activity in ring-porous than in diffuse-porous types of deciduous trees.

OBSERVATIONS—DENDROMETER RESULTS

One dendrograph and two dendrometers were attached respectively to three trees on April 1, 1940. The trees, hereafter to be designated as "A," "B" and "C" were 15, 17 and 12 inches DBH. respectively. To "A" was attached a dendrometer which measured changes in radius; to "B" was attached the dendrograph which recorded hourly and daily variation in diameter; and to "C" was attached a dendrometer which measured changes in diameter. The two dendrometers gave measurements at a magnification of 25 and the dendrograph was adjusted to magnify diametral changes 18 times.

The first radial and diametral changes were noted in "A" for the week ending May 20 and in "C" for the week ending May 27. This activity coincided with the time of full expansion of the leaves. Subsequent activity (table I and curves A and C) consisted of rises to maximal rates of increase which were reached in both trees during the week ending June 17. This was followed by essentially symmetrical falls in rate of increase which were continued into distinct losses due to contraction resulting from excess transpiration loss over ability of the roots to supply water. Tree "C" was one week later than tree "A" in initiation of diametral increase and one week later in showing contraction loss in diameter. Loss in diameter or radius

Radial Changes — Climatic Factors

Daily Reversible Variations

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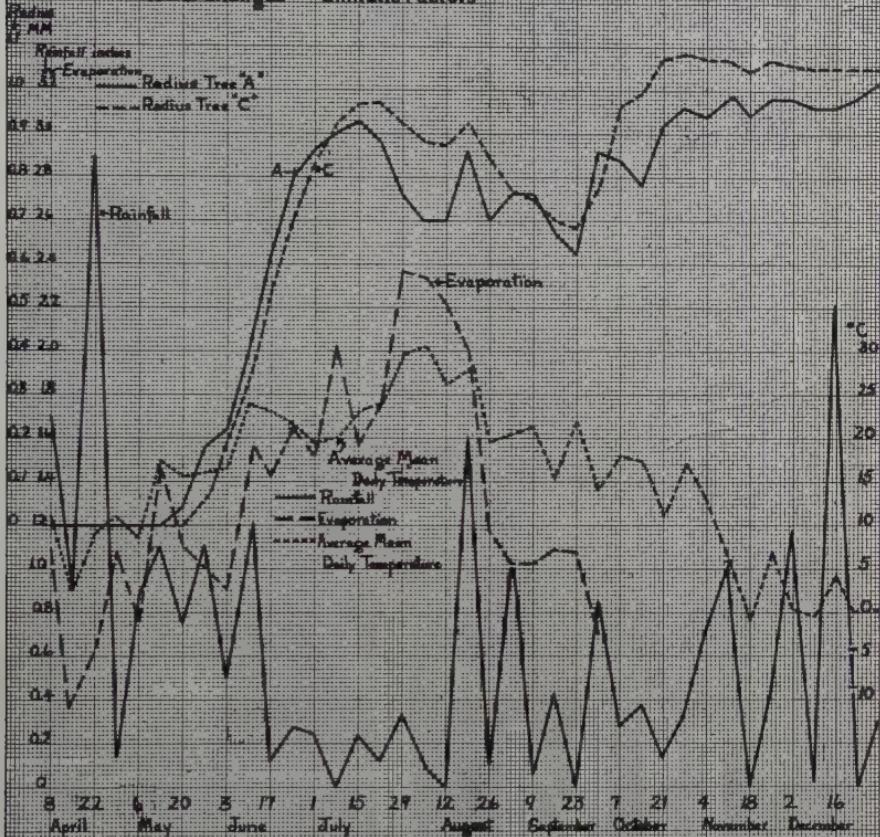
continued for 3 consecutive weeks. Rain during the night of August 18-19 was promptly followed by radial and diametral gains. But these were offset by equivalent or greater losses during the following week. The months of September and October were occupied by losses during some weeks and recoveries during others. Recoveries were associated with periods of rainfall and lowered temperatures and final recovery accompanying leaf-fall left both trees with radii slightly greater than those exhibited in mid-July when the first losses were registered. During the "dormant" months of November and December both trees registered slight losses and recoveries. On December 30, the date of the last reading concerned in this paper, tree "A" had a radius 0.06 mm greater than at the time of leaf-fall and 0.10 mm greater than at the cessation of radial increases in mid-July. Tree "C," on the other hand exhibited a radius 0.03 mm less than at leaf-fall and 0.082 mm greater than at cessation of increases in mid-July. The total net change in radius from April 1 to December 30 was 1.02 mm in tree "A" and 1.052 mm in tree "C."

Weekly rainfall, mean weekly temperature, and total wekly evaporation are shown in curves accompanying those for radial changes. The 1940 season may be considered to have been considerably less favorable than usual, at least from the standpoint of rainfall. Final rainfall reports from the U. S. Weather Bureau Station which is approximately 6 miles from the location of the trees under study showed a rainfall below normal for every month of the growing season except that of May. Data are presented in table II where it will be noted that rainfall ranged from 26.94% of normal in July to 87.91% of normal in August.

DENDROGRAPH OBSERVATIONS

Results from tree "B" upon which the dendrograph was used are shown as curves of daily reversible variations. The curves show essentially straight lines until the week ending May 13, when daily reversible variations first appeared. These variations presented a curve with daily maxima about 6 a. m. and daily minima about 4 p. m. They showed a range of approximately 0.111 mm. These reversible variations appeared in tree "B" one week before radial increases was observed in tree "A" and two weeks before activity was recorded in tree "C." They were not accompanied by any appreciable net diametral change. Unfortunately, the data for the next four weeks

TABLE I

Trunk changes and Meteorological Data

Week ending	Radial or Diametral Changes				Meteorological Data		
	Tree A. 15″ DBH. Radius for Current Week	Total Radius	Tree C. 12″ DBH. Diameter Current	Total Radius	Av. Mean Daily Temp.	Rainfall inches	Evaporation inches
4- 8-40	0 mm	0 mm	0 mm	0 mm	11.16°C	1.71″	1.094″
4-15-40	0	0	0	0	3.5	0.92	0.374
4-22-40	0	0	0	0	9.4	2.88	0.617
4-29-40	0	0	0	0	11.3	0.14	1.106
5- 6-40	0	0	0	0	8.7	0.88	0.769
5-13-40	0	0	0	0	17.0	1.10	1.465
5-20-40	0.040	0.040	0	0	15.7	0.75	1.112
5-27-40	0.140	0.180	0.140	0.070	16.2	1.11	1.096
6- 3-40	0.080	0.220	0.240	0.19	16.1	0.50	0.914
6-10-40	0.180	0.400	0.300	0.340	24.4	1.21	1.576
6-17-40	0.220	0.620	0.400	0.540	23.4	0.12	1.430
6-24-40	0.180	0.800	0.320	0.700	21.8	0.27	1.644
7- 1-40	0.060	0.860	0.260	0.830	19.6	0.24	1.528
7- 8-40	0.040	0.900	0.180	0.920	20.1	0.00	2.025
7-15-40	0.028	0.928	0.092	0.966	22.9	0.24	1.570
7-22-40	−0.048	0.880	0.004	0.970	24.3	0.12	1.751
7-29-40	−0.120	0.760	−0.096	0.922	29.6	0.33	2.372
8- 5-40	−0.060	0.700	−0.080	0.882	30.7	0.08	2.346
8-12-40	0.000	0.700	−0.020	0.872	26.3	0.00	2.223
8-19-40	0.160	0.860	0.100	0.922	27.8	1.60	2.010
8-26-40	−0.160	0.700	−0.160	0.842	19.5	0.11	1.188
9- 2-40	0.060	0.760	−0.140	0.772	20.6	1.00	1.003
9- 9-40	0.000	0.760	−0.040	0.752	21.3	0.06	1.022
9-16-40	−0.088	0.672	−0.100	0.702	15.3	0.43	1.095
9-23-40	−0.052	0.620	−0.040	0.682	21.8	0.00	1.080
9-30-40	0.240	0.860	0.180	0.772	14.2	0.85	0.703
10- 7-40	−0.020	0.840	0.380	0.962	18.0	0.28	¼ leaves gone
10-14-40	−0.060	0.780	0.060	0.992	17.4	0.37	½ leaves gone
10-21-40	0.140	0.920	0.160	1.072	11.2	0.13	¾ leaves gone
10-28-40	0.040	0.960	0.020	1.082	17.1	0.33	All leaves gone
11- 4-40	−0.040	0.920	−0.020	1.072	13.2	0.72	
11-11-40	0.060	0.980	0.000	1.072	6.6	1.02	
11-18-40	−0.040	0.940	−0.060	1.042	−1.1	0.00	
11-25-40	0.040	0.980	0.060	1.072	7.2	0.44	
12- 2-40	0.000	0.980	−0.020	1.062	0.22	1.17	
12- 9-40	0.020	0.960	−0.020	1.052	−0.55	0.01	
12-16-40	0.000	0.960	0.000	1.052	4.15	2.21	
12-23-40	0.020	0.980	0.000	1.052	3.25	0.00	
12-30-40	0.040	1.020	0.000	1.052	6.03	0.35	

TABLE II

Rainfall in Relation to Normal. Growing Season 1940

Month	Rainfall	Normal-Expected	Percentage of Normal
May	4.30 inches	3.89 inches	110.54%
June	1.88	3.62	51.93
July	0.90	3.34	26.94
August	2.91	3.31	87.91
September	1.06	3.40	31.17
October	1.15	2.78	41.36
Total	12.20	20.34	59.98

were lost due to difficulties in manipulation. By June 17, when the next data were obtained for tree "B," net diametral change had reached its maximum rate in all three trees under study, but daily reversible variations were not appreciably different in extent as compared with those on May 13. Daily reversible variations continued until November 4, when the dendrograph was dismounted for the season. Maximum daily reversible variations showed a difference of 0.222 mm between the early morning and late afternoon diameters. This difference was attained daily for the weeks ending July 29 and August 5. A difference of 0.2 mm was shown for the week preceding these two. Reference to curves and to table I will show that these weeks are the period of lowest rainfall, highest temperature and highest evaporation. They are also the time of radial losses in trees "A" and "C." By November 4, the curve of daily reversible variations exhibited nearly a straight line, approaching the condition shown at the beginning of the season.

DISCUSSION

The use of the terms "spring wood" and "summer wood" in connection with the teaching of wood anatomy has left in the minds of most students the impression that in trees in general there is diametral growth during the major part of late spring, summer and early autumn of each year. When one observes a cut section of most of our broadleaf trees, the diametral ratio of spring wood to summer wood certainly leaves the impression that much more wood is formed during the summer than during the spring.

On the other hand, when the environmental conditions which favor diametral increase in wood are taken into account, it becomes

obvious that while the time of wood formation is most likely to vary considerable from year to year, late spring and early summer are more often the periods most favorable in our region for diametral growth. The most important external factors controlling wood formation which are variable on the same site from season to season and day to day are temperature, evaporation rate and available water. The first is, in our area, most likely to control time of bud activity and thereby the time of initiation of diametral increase while the latter two more often control its duration. The effect of these factors will, no doubt, vary somewhat in different species of trees, the variation being related to differences in response of the species in elaborating, translocating and utilizing growth promoting substances.

In the earlier part of the season, when water supply is most likely to be adequate, temperature is more likely to become the limiting factor, whereas in the later part of the season, when temperature is adequate, available water and evaporation become the limiting factors. The relation of these factors is not a simple one: as temperature increases the demand for water to supply evaporation losses increases also and thus makes available water a still more potent limiting factor. This is well illustrated by the results shown in the curves for tree growth when compared with the curves for these environmental factors. From May 6 to June 10 when available water was adequate, due to excess rainfall in May (table II shows 110.54% of normal for this month), to supply both transpiration demands and metabolic needs, and food, both reserve and current construction, was adequate, temperature was a more important limiting factor. This is evidenced by the fact that the curve for rate of growth rises with that of temperature, but as the temperature continues to rise with available water becoming inadequate in relation to evaporation demand, the growth rate falls. As the factor-complex becomes less and less favorable after mid-June, diametral changes are transformed from gains into losses.

The effect of light cannot be left out of account. During a cloudy period when light is reduced, photosynthetic processes may be slowed down so that less wood-forming materials may be constructed but, on the other hand, the effect of reduced light on the turgidity of the guard cells of the stomata may be such as to cutdown transpira-

tion demand and thus permit water available for diametral increase to be more nearly the optimum.

If temperature and available water are at their optimum, then available light may become the limiting factor and diametral increase may then show a direct relation to the number of cloudless hours per light-portion of the day. It is, therefore, readily seen that diametral increase is not controlled by any one factor of the environment, but by a combination of factors all of which are variable. If any one of the factors changes, then the effect of the factor-complex changes and it is this factor-complex to which, in the final analysis, the plant must respond. The relation of diametral changes to these factors is thoroughly discussed by MacDougal (6).

Temperatures for any sustained period of time in the spring of 1940 remained low late into the season so that cambial activity, insofar as diametral increase in the trunk of trees is concerned, was late in starting. Rainfall, while short in the winter, was adequate in spring until mid-June. By July a pronounced drought, accompanied by higher temperatures than normal, had set in. Both the rainfall deficit and the high temperatures continued until the middle of August when a short respite from the more rigorous climatic conditions of the previous two months occurred. The autumn and early winter continued mild and relatively dry. All of this is sharply reflected in the growth curves. Diametral increase began shortly after the middle of May and, while temperature and moisture were approaching their joint optimum, the growth changes rose steadily to their maximum rate about the middle of June. After the middle of June, with temperature satisfactory but available moisture sinking below the optimum and rapidly approaching drought status, growth increases fell off in rate to near the vanishing point by the middle of July and gave way to net losses due to contraction resulting from lowered turgidity during the hot and rainless period from the middle of July to the middle of August. Contraction of trunks due to loss of turgidity resulting from inability of roots to supply transpiration demand has been noted in all trees studied (MacDougal, 7).

Just what proportion of the diametral changes are due to actual increase in wood and what to variations in turgidity of both wood cells and those of the cortex is not indicated by the results in this study. It is probable that most of the changes in diameter after mid-July are turgidity changes. The daily reversible variations are like-

wise chiefly turgidity changes. It is worthy of note in this connection that while both trees "A" and "C" showed net radial losses during the period from July 15 to September 23 and shorter periods of loss after the latter date, recovery in both trees by the end of the observation period (December 30) had more than made good the earlier losses and the radii were greater in each case than when the mid-July losses began to occur. The losses and recoveries during November and December, following the time when all leaves had either fallen or were dead, is more difficult to understand. In all cases the losses were small and are related to rainless periods of unusually mild temperature.

That diametral changes do show an immediate and close relation to available moisture is shown by results in irrigation experiments conducted by MacDougal (7). Irrigation of a specimen of *Quercus agrifolia* (an evergreen oak) which had shown no growth increase for 3 weeks resulted in diametral changes within 2 hours after application of the water.

The results of Diller (2) on annual ring formation in *Fagus grandifolia* in northern Indiana take on new significance in the light of the present results. He found that annual growth in Fagus showed a closer direct relation to rainfall for the month of June than for any other period and an inverse relation to temperature for the same month. In the present results it is shown that by far the greater proportion of annual growth for the year 1940 occurred during the month of June.

SUMMARY

1. Radial and diametral changes have been studied with dendrometers and dendrograph on three trees of *Fagus grandifolia*.

2. Growth changes were first noted coincident with the time when leaves attained full expansion, this occurring in 1940 about the middle of May.

3. Radial increases rose steadily to maximal rates which occurred in all three trees during the week ending June 17.

4. Radial increases steadily decline in rate reaching the zero point shortly after July 15.

5. Radial losses due to reduced turgidity resulting from excess of transpiration over ability of roots to supply water occurred from July 15 to August 12. Weekly periods following this date showed

alternating losses and recoveries closely correlated with rainfall and evaporation rate.

6. Both trees to which dendrometers were attached showed slightly longer radii at time of leaf-fall than at time of cessation of growth changes.

7. Between time of leaf-fall and the end of the observation period slight losses and recoveries also occurred. In one tree the end of the observation period saw a slight gain over the radius at leaf-fall while in the other there was a slight net loss.

8. Daily reversible variations were registered by the dendrograph one week before growth activity began and continued in greater or lesser degree until the dismantling of the instrument on November 4.

9. The daily curve showed maximum diameters about 6 a. m. and minima from 4 to 6 p. m., more often the latter time.

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RELATION OF ANNUAL RING FORMATION TO RAINFALL

As Illustrated in Six Species of Trees in Marshall County, Indiana

By Ray C. and Gladys M. Friesner

The rate of growth of trees is dependent upon a number of factors, some internal and hereditary and others external and environmental in character. Variations in growth from day to day and year to year within the same individual are related more definitely to environmental than to internal factors. Of the environmental factors, light, temperature and available water are perhaps the most important. The relation of tree growth to any one of these three factors is not simple or direct but rather a relation to the factor-complex. At any time when any two of these factors are adequate while the third is inadequate to support maximum growth, then that third factor becomes the limiting factor toward which there is the most direct relation on the part of the plant. In our area, during the normal growing season, temperature and light are more often adequate with available water becoming the limiting factor. It is thus seen that growth curves of trees will more often show a relation to rainfall curves than to those for any other single factor. Pearson (14) has pointed this out clearly.

The relation of growth curves to rainfall is not a simple one. Such factors as the following enter to make the relation complex: the time of year when the rains come, the proportion which comes during the growing season, how well they are distributed over the growing season, the topography and its relation to run-off, the character of the soil and its ability to store water from times of abundant to times of inadequate rainfall.

Douglas (4) has shown a definite relation between the width of annual rings in western conifers and rainfall. Fuller (6) has shown that there is a positive correlation between growth and rainfall in 46 out of 66 years in the case of a single section of *Quercus borealis maxima* and that in an additional 10 years the growth is influenced by a "carry-over of rainfall excess or deficiency from the preceding year." Robbins (15) found that in oak the mean monthly temperature of May and June shows an inverse relation to annual increase

in growth rings and that there is a close relation between amount of annual growth and the rainfall for the months of March through June. He also found that rainfall deficiencies or excesses will vary in their effect upon growth depending upon the time of year when they come. If they come in the spring their effect will be reflected in the growth of the same year but if they come chiefly in late season their effect will be more noticeable the following year. Diller (3) found that growth in *Fagus grandifolia* shows an inverse relation to temperature for the month of June and a direct relation to rainfall for the same months. This fits well with the results obtained during 1940 from dendrometer and dendrograph studies on Fagus (5) in which it is clearly shown that the great majority of growth in this species occurs during the month of June. Previous work done in our laboratory on 11 trees of *Quercus alba,* 17 of *Q. montana,* 16 of *Q. velutina* and 9 of *Q. borealis maxima* (Kleine, Potzger, Friesner, 9) showed that there is a very close correlation between annual growth and rainfall for the months of June, July and August. This work was done on sites with considerable relief and hence subject to execessive run-off. It is thus unlikely that any appreciable reserve of water can be stored in the soil during the dormant season. It is, therefore, all the more apparent that there should be a relation between growth and rainfall during the growing season. Diller (3) found that drought years show their effect the following year while the results of Kleine, Potzger and Friesner (9) indicate that the time when drought-year effects will be apparent depends upon the time of year when the drought occurred and also upon the topography of the site where trees are growing. If the drought is in late spring and early summer its effect will be apparent during the present season. If it comes in autumn or winter it may have an effect the following season if the site is such as to be able to store up reserves of water, but if it is such that run-off is great or for any reason little reserves can be stored, it may show no independent effect at all. This was well shown in the studies of Lodewick (10) on long-leaf pine.

MacDougal and Shreve (13) found that growth data from stump sections of *Pinus radiata* showed correlation with total annual rainfall in 65% of the years. They found that no periods of seasonal rainfall showed any correlation with average growth of trunk even when rainfall for the growth period and one preceding month was con-

sidered. In redwood the correlation between total rainfall and growth was 64% and that between rainfall from December to September was 71%. Antevs (1) has shown that whether or not there is a correlation between tree growth and rainfall depends upon whether available water is on the "dry limit," i. e. whether it has become the limiting factor. When available water becomes the limiting factor tree growth shows a correlation in the Great Basin in 75% of the years. Lodewick (10) found 64% corelation between diametral growth in long-leaf pine and rainfall for the period March 1 to October 15 and 73% if the rainfall period is shortened to begin March 16.

Avery, Creighton and Hock (2) found very little positive correlation between annual ring formation in hemlock and rainfall for either August-February or March-July. Only a slight inverse correlation was found for mean March-July temperature.

Goldthwait and Lyon (8) concluded that the total rainfall absorbed by the soil during the growing season (May-July) was the most important member of the complex of climatic factors affecting growth in white pine. Residual effects from the snowless period of one year are sometimes reflected in the amount of growth next year. Lyon (12) studying four species of evergreen conifers, one deciduous conifer and one deciduous broadleaf tree found varying degrees of correlation between growth and rainfall and temperature. White pine proved to be more sensitive to water supply than any others studied. It showed a positive correlation between growth and rainfall for various combinations of months and also with temperature of the early spring. Scotch pine showed closest correlation with April-August rainfall, Norway spruce with March-May rainfall while Austrian pine showed closer correlation with rain which fell prior to the growing season. Of the deciduous trees European larch showed the closest correlation with water supplied by abnormally high March temperatures and with air temperatures for May. Red oak showed closest correlation with rain which fell during its growing season. This agrees with our earlier results in an area of high relief (Kleine, Potzger, Friesner, 9). In an earlier study Lyon (11) found that growth in hemlock showed strong correlation with rainfall in years of unusual drought or unusually well watered years but little correlation in years when rainfall was little less or little more than usual. Schumacher and Day (16) concluded that hem-

lock, some stands of long-leaf pine and some of short-leaf pine showed little significant correlation with average monthly rainfall, while other stands of both species of pine showed significant correlation with the average monthly rainfall of 15-month periods from June of one year to August of the next year. Oak data from North Carolina showed a correlation to both average monthly rainfall and its distribution.

MATERIALS AND METHODS

Sections were cut from stumps and farther up the trunks of 17 specimens of *Quercus borealis maxima* (Marsh) Ashe, 4 specimens of *Quercus alba* L., 6 specimens of *Fraxinus americana* L., 2 specimens of *Acer saccharum* Marsh., and 1 specimen each of *Liriodendron tulipifera* L. and *Carya cordiformis* (Wang) K. Koch. The sections varied in age but only 40 years of growth, i. e. 1900 to 1939 inclusive were used from each inasmuch as rainfall data were available only for that period. The sections were cut from a forest located on the south side of Road 10, 8 miles west of the junctions of Roads 31 and 10. The location is thus in Marshall county, 8 miles west of Argos, Indiana.

Rainfall data were secured from the U. S. Weather Bureau station located in Plymouth approximately 9 miles northeast of the forest in which the trees under study grew. Rainfall curves were plotted for the calendar year, for the year beginning November 1 and ending October 31, for the periods May-August, June-August and June.

Growth as shown by annual ring width was measured along 8 equidistant radii of each section of each species. Measurements were made under an 8X magnifier and to the nearest quarter of a millimeter (the ruler used was graduated into half-millimeters). Curves were plotted for the sum of the 8 radii for each section individually and for the average of all sections of the same species. Glock (7) states that the best record of the effectiveness of growth factors upon growth is obtained by averaging the measurements from all radii studied. He used 6 as an effective number. In the present paper curves are drawn from the sums (not averages) of 8 radii for each section. Lodewick (10), on the other hand, found no striking difference between results obtained from 4 radii and from only 1 radius.

OBSERVATIONS AND RESULTS

The percentage of correlation between the annual growth curve of each tree specimen and the rainfall curves for 5 different periods of the year is shown in table I. It will be seen that the highest percentage of correlation between growth in *Quercus borealis maxima* (17 specimens) and rainfall occurs most often for the period June-

TABLE I

Percentage of correlation between growth and rainfall

Tree	Annual	Percentage of Correlation Nov.-Oct.	May-Aug.	June-Aug.	June
Quercus borealis maxima					
39- 1	48	50	51	55	39
39- 2	51	50	46	48	47
39- 5	48	44	49	52	55
39- 6	48	53	55	58	55
39- 8	48	43	45	51	51
39- 9	66	70	68	74	55
39-11	58	53	55	54	67
39-13	54	67	61	64	64
39-17	48	56	58	58	64
39-18	79	86	77	67	51
39-19	63	76	67	64	58
39-24	66	76	77	74	55
39-26	45	50	48	58	64
39-28	57	60	58	67	61
39-29	66	73	70	74	67
39-30	45	48	55	52	58
39-31	51	59	58	68	58
Quercus alba					
39- 3	52	58	52	55	48
39-23	60	79	67	77	68
39-25	64	59	65	68	55
39-27	67	76	74	74	61
Fraxinus americana					
39- 4	48	67	61	61	60
39-14	54	67	61	71	48
39-15	42	57	71	71	61
39-16	57	64	67	77	68
39-20	66	55	67	68	51
39-22	78	65	80	61	74
Acer saccharum					
39-10	60	56	58	57	47
39-12	54	57	58	61	63
Carya cordiformis	51	50	40	45	52
Liriodendron tulipifera	67	67	61	74	61

August with the single month of June running a close second. The lowest degree of correlation occurs most often between annual growth and total annual rainfall. These results are in agreement with those obtained earlier in our laboratory for several species of *Quercus* growing in the more dissected area of south central Indiana (9). In the 4 specimens of *Quercus alba* the highest percentage of correlation between annual growth and rainfall occurs for the period November-October with almost as high for the period June-August. The lowest percentage of correlation comes more often for this species in June. The small number of specimens studied in this case do not warrant definite conclusions. The 6 specimens of *Fraxinus americana* show the highest percentage of correlation more often for June-August with May-August a close second. The lowest percentage of correlation is more often with the annual rainfall. So few specimens of *Acer saccharum, Carya cordiformis,* and *Liriodendron tulipifera* were available that conclusions are not warranted regarding them. The true degree of correlation between the width of annual rings and rainfall is really higher than the percentages shown in table I indicate. This is due to "carry-over" effects which occur under certain conditions discussed below in connection with tables VI-VIII. Two definite periods of "carry-over" effects were found, viz. 1921-23 and 1929-1932.

Table II shows the results when an attempt is made to correlate growth with the years when rainfall for the various periods is conspicuously more than the preceding year. The figures given show the percentages of the years having conspicuous rainfall increases when growth in each individual tree is also greater than the preceding year. It will be seen that the percentages range for the various trees and the various rainfall periods from 25 to 100. In years when rainfall for the calendar year is 10 inches more than for the preceding year 25% to 75% of such years reveal an increase in growth over the preceding year. The average for all 31 specimens is 50%. In years when rainfall for November-October is 10 inches more than for the preceding year, growth is also more in an average for all specimens of 67% of the years. In years when rainfall for May-August is 5 inches more than for the same period of the preceding year, growth is also more in an average for all specimens of 70% of the years. When the rainfall is 5 inches more for the period of June-August the percentage is 59. The highest percentage is shown when

TABLE II

Correlation between growth and rainfall for years when rainfall is conspicuously more than the preceding year. Figures are percentages of the years when growth is also greater than the preceding year.

Tree	Annual 10 ins. more	Nov.-Oct. 10 ins. more	May-Aug. 5 ins. more	June-Aug. 5 ins. more	June 3 ins. more
Quercus borealis maxima					
39- 1	25	75	100	75	40
39- 2	50	50	50	75	40
39- 5	75	50	25	50	80
39- 6	50	75	100	100	40
39- 8	50	25	25	50	60
39- 9	50	100	100	75	100
39-11	25	50	50	25	80
39-13	50	100	100	75	80
39-17	25	50	75	50	80
39-18	50	100	100	75	80
39-19	50	75	75	50	80
39-24	50	75	75	50	80
39-26	50	75	75	50	80
39-28	50	75	75	50	80
39-29	75	75	75	75	80
39-30	50	50	75	50	80
39-31	50	50	75	50	80
Quercus alba					
39- 3	50	75	75	50	80
39-23	50	50	75	50	80
39-25	50	100	100	75	100
39-27	75	75	75	75	80
Fraxinus americana					
39- 4	25	50	50	25	60
39-14	75	75	75	75	60
39-15	50	75	75	50	60
39-16	50	100	100	75	100
39-20	75	75	75	50	80
39-22	25	50	75	25	60
Acer saccharum					
39-10	50	50	50	50	60
39-12	50	50	75	75	20
Carya cordiformis	50	50	75	50	80
Liriodendron tulipifera	75	75	75	75	80
Average % of Years	50	67	70	59	72

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June rainfall is 3 inches more than for June of the preceding ye
viz. 72%. When these figures are analyzed more closely it will
found that the percentage of correlation between growth and rain
in years when rainfall is conspicuously more than for the preced
year depends upon whether the increase in rainfall follows a y
when rainfall for the period under consideration was deficient
approximately normal. If available water is already near its optim
then an increase is of little consequence; but if available water
near the "dry-limit," then an increase is of great consequence. T
data in table II do not separate these two factors. Further light v
be thrown on this point by the data in table IV.

Table III presents results when annual growth is correlated w
rainfall in years when the latter is conspicuously less than in
preceding year. It will be seen that in years when rainfall for
calendar year is 10 inches less than the preceding year, growth is a
less in an average for all specimens of 62% of the years. Wl
rainfall for the period November-October is 10 inches less than
preceding year the average percentage of years with reduced grov
is 82. In years when rainfall for May-August is 5 inches less tl
for the same period of the preceding year, growth is also less in 7
of the years. When rainfall is 5 inches less for June-August tl
for the same period of the preceding year, growth is also less in 7
of the years. When rainfall for June is 3 inches less than June
the preceding year, growth is also less in 70% of the years.

A more detailed consideration of these percentages reveals t
a reduction in rainfall as such is not the critical factor controll
growth. The important factor is whether the reduction in rain
follows a year when rainfall was above normal or a year when it
about or below normal. If the reduction in rainfall brings the wa
available for growth to the point where it becomes a limiting fac
then a high degree of correlation between growth and rainfall
found. This point will be further illuminated in table V and als
tables VI-VIII.

It should be expected that growth is likely to be affected by c
spicuous reductions in rainfall in more years than by conspicu
increases. A comparison of results in table II and III shows
this appears to be true except for the month of June. When rain
for the calendar year is 10 inches more than the preceding y
growth is more in 50% of the years; but when rainfall is 10 inc

TABLE III

Correlation between growth and rainfall for years when rainfall is conspicuously less than the preceding year. Figures are percentages of the years when growth is also less than the preceding year.

Trees	Annual 10 ins. less	Nov.-Oct. 10 ins. less	May-Aug. 5 ins. less	June-Aug. 5 ins. less	June 3 ins. less
Quercus borealis maxima					
39- 1	16	0	30	75	25
39- 2	33	50	30	50	75
39- 5	16	0	30	50	50
39- 6	16	0	30	75	25
39- 8	33	0	30	50	50
39- 9	66	100	90	75	75
39-11	84	100	90	75	100
39-13	50	100	90	100	75
39-17	66	100	90	75	75
39-18	66	100	90	100	75
39-19	66	100	90	75	75
39-24	66	100	90	75	75
39-26	66	100	75	75	75
39-28	50	100	75	50	50
39-29	66	100	90	100	75
39-30	50	100	60	50	50
39-31	66	100	90	75	75
Quercus alba					
39- 3	84	100	60	50	75
39-23	84	100	90	75	75
39-25	84	100	90	100	75
39-27	66	100	90	75	75
Fraxinus americana					
39- 4	84	100	75	75	100
39-14	66	100	90	75	75
39-15	50	100	90	100	100
39-16	84	100	90	75	75
39-20	84	100	75	50	75
39-22	84	100	90	75	100
Acer saccharum					
39-10	66	50	75	100	75
39-12	66	50	60	25	25
Carya cordiformis	66	100	75	50	75
Liriodendron tulipifera	84	100	75	75	75
Average % of Years	62	82	74	72	70

less, growth is less in 62% of the years. When rainfall for Novem ber-October is 10 inches more, growth is more in 67% of the years but when rainfall is 10 inches less, growth is less in 82% of the years. When rainfall for May-August is 5 inches more, growth is more in 70% of the years; but when rainfall is 5 inches less, growth is less in 74% of the years. When rainfall for June-August is 5 inches more, growth is more in 59% of the years; but when rainfall is 5 inches less, growth is less in 72% of the years. When rainfall for June is 3 inches more, growth is more in 72% of the years; but when rainfall is 3 inches less, growth is less in 70% of the years. These data are brought together in table III-A.

TABLE III-A

Relation between correlations of growth and rainfall in years when rainfall is conspicuously greater than the previous year and similar correlations when rainfall is conspicuously less than the preceding year.

Rainfall Changes	Percentage of years showing correlation. Average for all tree specimens	
	When rainfall is more than previous year	When rainfall is less than previous pear
Annual rainfall differs from previous year by 10 inches or more	50	62
November-October rainfall differs from previous year by 10 inches or more	67	82
May-August rainfall differs from previous year by 5 inches or more	70	74
June-August rainfall differs from previous year by 5 inches or more	59	72
June rainfall differs from previous year by 3 inches or more	72	70

Table IV shows the percentage of individual trees which showed increased growth in years when there was conspicuous increase in rainfall over the preceding year. It will be seen that except for the years 1909, 1919 and 1929, high percentages of the trees showed increased growth in years which were characterized by conspicuous increases in rainfall. These three years stand out conspicuously for the small percentage of individual trees which responded to increased rainfall by increased growth. The rainfall in both 1909 and 1919 for the periods under study was unusually high and followed corresponding periods of normal or only little below normal rainfall

TABLE IV

Correlation between growth and rainfall for years when rainfall is conspicuously more than the preceding year. Figures are the percentages of trees showing greater growth than the preceding year.

Rainfall Change	Years	Percentage of Trees Showing Greater Growth than Preceding Year		
		Q. b. maxima	Q. alba	F. americana
Annual rainfall 10 inches more than previous year	1909	30	50	34
	1916	60	75	68
	1926	96	100	84
	1929	12	0	17
Nov.-Oct. 10 inches more than previous year	1916	60	75	68
	1919	42	25	34
	1926	100	100	84
	1935	78	100	100
May-Aug. 5 inches more than previous year	1912	78	100	50
	1919	42	25	34
	1926	94	100	84
	1935	78	100	100
June-Aug. 5 inches more than previous year	1909	30	50	34
	1912	78	100	50
	1919	42	25	34
	1926	94	100	84
June 3 inches more than previous year	1911	90	100	84
	1916	60	75	68
	1924	66	100	100
	1937	84	100	84

for the preceding year. Annual rainfall was 32.41 inches for 1908 and 44.01 inches for 1909 while the normal for this area is about 34 inches. The June-August period of 1909, which likewise showed little correlation between increased rainfall and increased growth, showed 6.84 inches for 1908 and 13.02 inches for 1909 with the normal about 10 inches. Annual rainfall was 34.42 inches for 1918 and 40.09 inches for 1919. The May-August rainfall was 10.18 inches for 1918 and 17.16 inches for 1919 with the normal about 13 inches. The June-August rainfall was 5.62 inches for 1918 and 11.46 for 1919 with normal about 10 inches. While in this last period there was greater departure from the normal in the preceding year, the month preceding the beginning of the period (i. e. May, 1918) was above normal bringing available water during the growing period

TABLE V.

Correlation between growth and rainfall for years when rainfall is conspicuously less than the preceding year. Figures are percentages of tree showing less growth than preceding year.

Rainfall-Change	Year	Percentage of Trees Showing less, Growth than Preceding Year		
		Q. b. maxima	Q. alba	F. american
Annual rainfall 10 inches less	1910	60	100	100
than previous year	1917	73	100	100
	1922	6	0	34
	1928	42	75	51
	1930	60	100	84
	1934	72	100	100
Nov.-Oct. 10 inches less	1917	78	100	100
than previous year	1934	72	100	100
May-Aug. 5 inches less than	1910	60	100	100
previous year	1913	78	75	50
	1917	78	100	100
	1922	6	0	17
	1925	100	100	100
	1934	72	100	100
	1936	66	75	100
June-Aug. 5 inches less	1908	42	25	50
than previous year	1910	60	100	100
	1913	84	75	50
	1925	100	100	100
June 3 inches less than	1910	60	100	100
previous year	1912	24	0	50
	1917	78	100	100
	1925	100	100	100

in 1918 sufficiently near the optimum that its deficiency was felt. These data support the conclusion that increased rainfall fects growth relatively little when the increase is imposed upon previous amount already near the normal.

The reason for the low percentage of trees showing increas growth in 1929 as compared to 1928, even though there were o 10 inches more of rainfall in the latter year, is to be found in a ferent set of conditions from those that pertain in the years 1909 1919. Annual rainfall was 27.55 in 1928 and 38.68 in 1929 wh the normal is about 34. During these same years, however, the ra fall during the growing season (June-August) was 12.69 inches

1928 (the year with total reduced rainfall) and 11.06 inches in 1929. It is thus seen that June-August rainfall was above normal in both 1928 and 1929 and since that for 1928 was higher, increased growth could hardly be expected in 1929.

Table V shows the percentage of individual trees which showed decreased growth in years which showed conspicuous decreases for the various rainfall periods. It will be seen that the percentages are high for all periods for nearly all years. Conspicuous lack of correlation is found for the year 1922. A careful analysis of the conditions pertaining in 1921, 1922 and 1923 shows that rainfall effects may carry over from one year to the next. Rainfall for 1921 was much above normal from August on, but 1922 was below normal and 1923 above normal. Growth in 1922 increased over 1921 in spite of a 10-inch decrease in rainfall while in 1923 growth decreased over 1922 in spite of an increase of 8.1 inches in rainfall. Thus a period of above normal rainfall was reflected in increased growth the following year during which rainfall was over 10 inches less and almost as far below normal as the previous year was above normal, while the period of below normal rainfall (1922) was in turn reflected in decreased growth during the year following it when rainfall increased to above normal. The rainfall for the calendar years 1921, 1922 and 1923 was 40.89, 30.34 and 38.44 inches respectively. If the rainfall is calculated from August of one year to July of the following year we find a complete reversal of the rainfall curve and a complete correlation of it with the growth curve. The rainfall thus computed for 1920-21, 1921-22 and 1922-23 was 27.22, 42.44 and 31.24 inches respectively.

Tables VI-VIII show the amounts of rainfall change for each rainfall period when 90% of the specimens of *Quercus borealis maxima* (table VI), and 100% of the specimens of *Q. alba* (table VII) and 100% of the specimens of *Fraxinus americana* (table VIII) show either increased or decreased growth over the preceding year. It will be seen that in all cases except 1922, 1923 and 1931 increases in growth are correlated with increases in rainfall for all or nearly all of the month-combinations and decreases in growth are correlated with decreases in rainfall. Except for these years, rainfall for June-August always shows an increase over the same period of the preceding year when there is 90-100% agreement amongst the specimens from the standpoint of increase in growth and a decrease in rainfall

when there is a decrease in growth. The exceptions for 1922 and 1923 have been discussed above. That for 1931 is due to essentially the same factors. Total rainfall for 1930 and 1931 was 28.60 and 36.32 inches respectively while rainfall for the August-July combination of months for 1929-30 and 1930-31 was 35.01 and 27.32 inches respectively. It is thus seen that the rainfall for the latter month-combinations is the reverse for these years from that pertaining for the calendar year.

TABLE VI

Quercus borealis maxima. Correlation between growth and rainfall showing amount of rainfall change as compared to preceding year when 90% or more of the trees showed increase or decrease in amount of growth as compared to preceding year.

| Years | Annual | Rainfall Change as Compared with Preceding Year | | | |
		Nov.-Oct.	May-Aug.	June-Aug.	June
Growth Increase in inches					
1911	9	2	1.5	3.5	4.8
1915	0.29	–2	2.1	1.9	1.7
1922	–10	–2.8	–4.4	–4.6	–0.47
1926	15	13.7	9.2	5.6	2.5
1935	8.2	13.2	7.9	1.1	1.4
1937	2.3	4.7	3.6	4	4.1
Growth Decrease in inches					
1913	–3.3	–4.9	–6.7	–7	–0.15
1914	–5.7	–4.1	0.5	0.5	1.5
1918	6.4	–1.5	–2.3	–3.2	–0.01
1925	–7.3	–6.7	–7.9	–6.2	–5.3
1929	11	–0.8	–1	–1.6	–0.1

TABLE VII

Quercus alba. Correlation between growth and rainfall showing amount of rainfall change as compared to preceding year when 100% of trees showed increase or decrease in amount of growth as compared to preceding year.

| Years | Annual | Rainfall Change as Compared with Preceding Year | | | |
		Nov.-Oct.	May-Aug.	June-Aug.	June
Growth Increase in inches					
1902			16.3	11.8	–8.5
1907	4.4	5.8	2.5	2.6	–0.6
1911	8.4	2.2	1.6	3.5	4.8
1912	1.9	6.2	8.8	6	–3.4
1922	–10	–2.8	–4.8	–4.6	–0.4
1924	–6.2	–3.7	–0.8	0.4	4.3
1926	15	13.7	9.2	5.2	2.5

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TABLE VII—(Continued)

Years	Annual	Rainfall Change as Compared with Preceding Year			
		Nov.-Oct.	May-Aug.	June-Aug.	June
1932	1.3	2.1	1.3	2.8	-2
1935	8.2	13.2	7.9	1.1	1.4
1937	2.3	4.7	3.6	4	4.1
Growth Decrease in inches					
1901	-3.7	-2.6	-9.8	-7.1	-1.3
1910	-14.1	-8.1	-4.8	-6.3	-3.7
1914	-5.7	-4.1	0.5	0.5	1.5
1917	-16	-12	-8.9	-4.3	-6.8
1918	6.4	-1.5	-2.3	-3.2	-0.01
1923	8.1	3.2	4.1	3.8	-0.4
1925	-7.3	-6.7	-7.9	-6.3	-5.3
1929	11	-0.8	-1	-1.6	-0.1
1930	-10	-7.9	-3.9	-4	-1.5
1931	7.7	6.1	4.5	2.3	1.9
1933	2.4	7.1	-0.2	-3.9	-0.7
1934	-11	-2	-6.3	-0.1	0.6

TABLE VIII

Fraxinus americana. Correlation between growth and rainfall showing amount of rainfall change as compared to preceding year when 100% of trees showed increase or decrease in amount of growth as compared to preceding year.

Years	Annual	Rainfall Change as Compared to Previous Year			
		Nov.-Oct.	May-Aug.	June-Aug.	June
Growth Increase in inches					
1911	9	2	1.5	3.5	4.8
1915	0.29	-2	2.1	1.9	-1.7
1924	-6.2	-3.7	-0.8	0.4	4.3
1932	1.3	2.1	1.3	2.8	-2
1935	8.2	13.2	7.9	1.1	1.4
Growth Decrease in inches					
1910	-14.1	-8.1	-4.8	-6.3	-3.7
1917	-16	-12	-8.9	-4.3	-6.8
1925	-7.3	-6.7	-7.9	-6.3	-5.3
1934	-11	-20	-6.3	-0.12	0.6
1936	-5	-5.1	-8	-3.4	-2.3

DISCUSSION

From the foregoing data it is clear that there is no simple relationship between growth and rainfall for any conceivable combination of months. The data will support the conclusion that rainfall shows the highest degree of correlation when it becomes a limiting factor.

It is obvious that the important condition is that the plant have water available to it when it is needed and in amounts sufficient for these needs. During a growing season when evaporation demands are lower a higher percentage of available water is left for growing purposes. An increased rainfall imposed upon a previous rainfall already adequate will not be reflected in increased growth, but an increased rainfall imposed upon a previous year of deficiency will be likely to be reflected in growth increase. In a similar manner a decrease following a year of excessive rainfall will not necessarily show a decrease in growth but if the decrease follows a year when available water is already a limiting factor, decrease in growth is to be expected. It is entirely possible that light due to number of cloudless hours may become the limiting factor in years of excessive rainfall if the excess comes during the growing season. While rainfall occurring during the period June-August more often shows a correlation with growth in this study, it does not always do so. In some years an accumulated deficit prior to June may not be sufficiently offset by an excessive rainfall during these months and hence a great increase in this period over the corresponding period of the previous year will still show a decrease in growth over the preceding year. Conversely an accumulated excess prior to the growing period may carry the plants through a growing season receiving deficient rainfall.

It is obvious that much also depends upon the condition of the soil when the rain falls. High rainfall during some winters may be of much less value than during others. There will be a tremendous difference between frozen and unfrozen soil from the standpoint of the amount of water that can be absorbed and the percentage of the rain that must run off. This means that the time of year when the rains come will be a vital factor. The distribution of the rains over the year from the standpoint of frequency and severity also becomes a vital factor.

SUMMARY AND CONCLUSIONS

1. Correlation between width of annual rings and rainfall is studied in stump and stem sections from 17 specimens of *Quercus borealis maxima,* 4 of *Q. alba,* 6 of *Fraxinus americana,* 2 of *Acer saccharum* and 1 each of *Carya cordiformis* and *Liriodendron tulipifera* from Marshall county, Indiana.

2.   The highest percentage of correlation for most specimens was with rainfall for either June-August or the single month of June but individual exceptions are found in which the highest correlation is with other rainfall periods.   In the case of *Quercus alba* a slightly higher percentage of correlation occurs with the rainfall in the period November-October in 3 of the 4 specimens studied.

3.   When rainfall for one year or a particular period of that year is conspicuously greater than for the preceding year, growth is also greater in from 50 to 72% of the years; but when the rainfall for corresponding periods is conspicuously less than for the preceding year, growth is also less in from 62 to 82% of the years.

4.   When rainfall for one year or a particular period of that year is conspicuously greater or conspicuously less than for the preceding year, growth is greater or less respectively in a large percentage of the individual trees; but some years are found in which the percentage of individual trees showing such correlation is very small.   This lack of correlation is due to the distribution of rainfall failing to coincide with the vegetative year.

5.   In years when there is 90-100% agreement amongst the individual trees, increase in growth is correlated with increase in rainfall and decrease in growth with decrease in rainfall for nearly all month-combinations.   The correlation is perfect for June-August rainfall except for 1922, 1923, and 1931 during which years the rainfall for the month-combinations August to July of the following year forms perfect correlation.

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NOMENCLATORIAL CHANGES IN THE GENUS SOLIDAGO—CORRECTIONS

By RAY C. FRIESNER

In a recent note (Butler Univ. Bot. Stud. 4:196. 1940) 5 nomenclatorial changes were made in the genus Solidago. In making these changes several errors were made which it is here proposed to correct.

SOLIDAGO BOMBYCINA (Lunell) Friesner, l. c. Originally described by Lunell (Amer. Midland Nat. 2:59. 1911) as Oligoneuron. In my previous note I made an error in the ending of the species name using "um" when "a" should have been used. Dr. S. F. Blake has called my attention to the fact that Fedde (Bot. Jahresber. Just 42 (2):156, foot-note. 1918) made a transfer of this species to the genus Solidago but that under the International Rules his transfer (made in the form "An melius Solidago bombycina? Fedde) ranks as a provisional name and so is invalid.

SOLIDAGO GIGANTEA var. SALEBROSA (Piper) comb. nov. Originally described by Piper (Fl. Palouse Reg. 185. 1901) as a variety of *S. serotina*. In my previous note I omitted from the name the designation "var." Under International Rules this would be invalid as a varietal combination because of failure to designate the rank.

SOLIDAGO GRAMINEA (Wooten and Standley) Blake. In making my transfer of this species from Petradoria to Solidago I overlooked the fact that Dr. Blake had previously made it (Jour. Wash. Acad. Sci. 21:326. 1931).

SOLIDAGO TEXENSIS Friesner, l. c. In renaming Dr. Greene's *Euthamia pulverulenta* (Pittonia 5:17. 1902) because the name *Solidago pulverulenta* had already been used as a valid name (Nuttall, Gen. Am. Pl. 2:161. 1918), I gave Greene as parenthetical authority. Dr. Blake has pointed out that a parenthetical authority should not be used when a species is renamed.